RAC Product Design
Prof. Sanjeev Jain & Bhupinder Godara
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

Lecture - 08
Expansion devices

So, we looked at one of the most expensive parts of the air conditioning system which was the compressor so far and now, we are going to switch to perhaps or not so expensive part which is equally critical to the performance of an air conditioner and this is expansion device.

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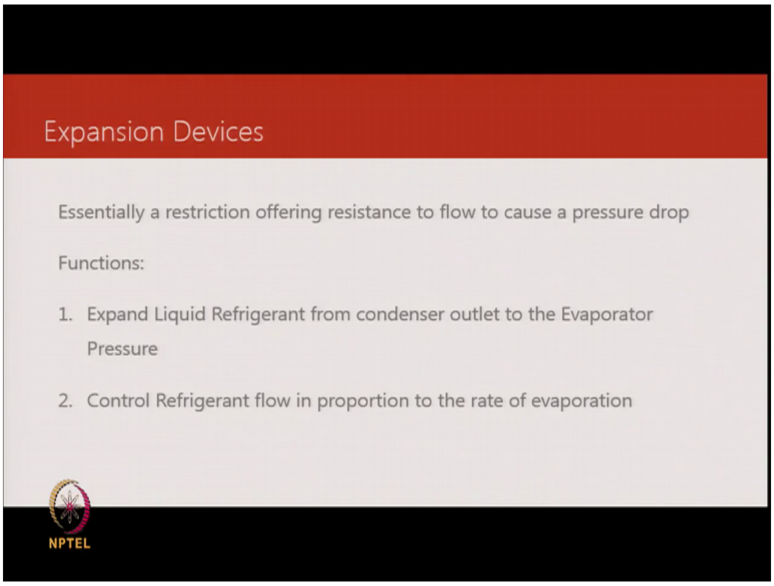

So, just like we have a pressure increased across an active compressor, we have a pressure drop across an expansion valve or rather the expansion device and then, we will have a separate nomenclature for expansion valves as we go to the next slide.

So, any restriction can be used as an expansion device. We are trying to prevent a refrigerant flowing freely. So, any restriction that we create is an expansion device. The function of the expansion devices, number 1 to make refrigerant flow at a certain rate to the evaporator, so, it is like a control device. The rate of heat rejection in the evaporator has to be matched by a corresponding mass flow rate of the refrigerant.

So, that is one function which is met by the compressor together with the expansion valve. There is another function which is the pressure drop that we need. We have liquid vapour, the liquid refrigerant and we want something to which we can reject the heat from the air conditioned space or from the refrigerated space. So, we need to get to a temperature lower than the temperature of the body from where we want to remove heat and that is accomplished by dropping the pressure which happens across the expansion device.

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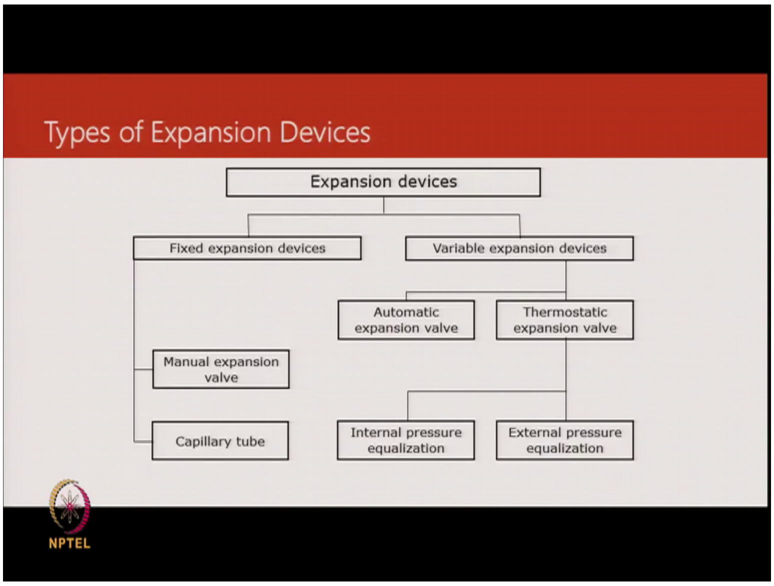

Now, there are several types of expansion devices the first category is fixed type of expansion devices which means there is no variation in the restriction that they offer. So, one of the easiest way is to look at an expansion device which is fixed as a capillary. You have a certain length, you have a certain diameter and the restriction that will offer is then constant. The flow rate of the refrigerant will depend of course on what is the pressure at the inlet, what the pressure is at the exit in some cases, but it will depend purely as a physical property of a fixed orifice and a fixed length.

We could also have something equivalent to a throttled, manually throttle expansion valve like a tap and you can control the flow rate. So, manually you could control the flow rate of refrigerant whether manual throttling device or manual expansion valve and then, we have a variable expansion devices which have of two major types; automatic expansion valve and thermostatic expansion valve, where the thermostatic expansion valve, we have another two categories which is internal equalization of pressure and external equalization of pressure. Is it clear?

Now, capillary I do not have a picture, but it is very easy for you to imagine this term. A thin tube with a diameter which is some 1 millimeter, 2 millimeter length and somewhere from 35 inches to 55 inches used in most low cost refrigeration systems. So, in your domestic refrigerator, there is a capillary.

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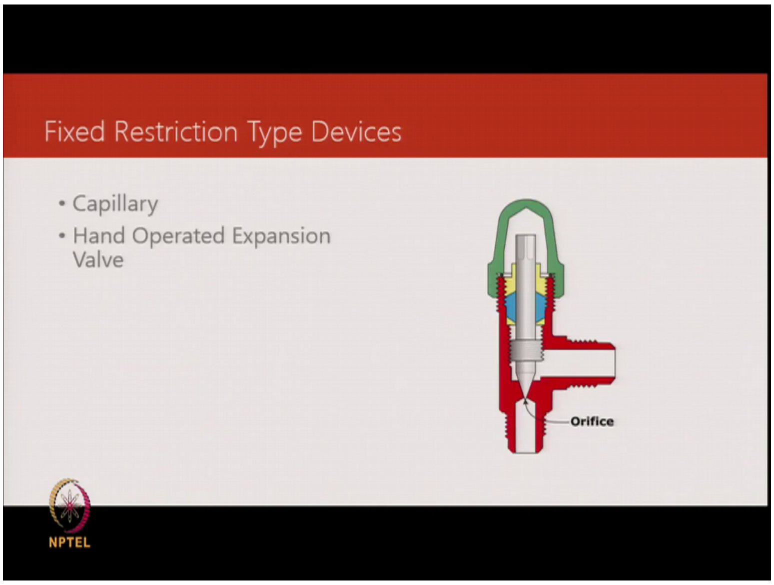

In your normal air conditioner split system of one and a half ton that you use in your homes, there would be a capillary. It is a lowest cost expansion device and still pretty effective. When you are targeting a fixed point performance, it is possible to optimize the capillary dimensions such that you are able to match the pressure drop needed for those operating conditions. It is also possible to take care of some of the adverse conditions by doing proper sizing, then we have the hand operated expansion valve that you see in this picture and if you relate to the cross-section of a tap, it is exactly that you have a stem.

So, this is the stem, this cap is there because we do not want refrigerant leaking. So, once we adjusted it we would put this cap, so that no refrigerant can leak between the seal of the shaft and the outer body. The pressure drop really happens between this point and the body. So, we can move manually, the shaft up and down and thereby alter the opening that is available.

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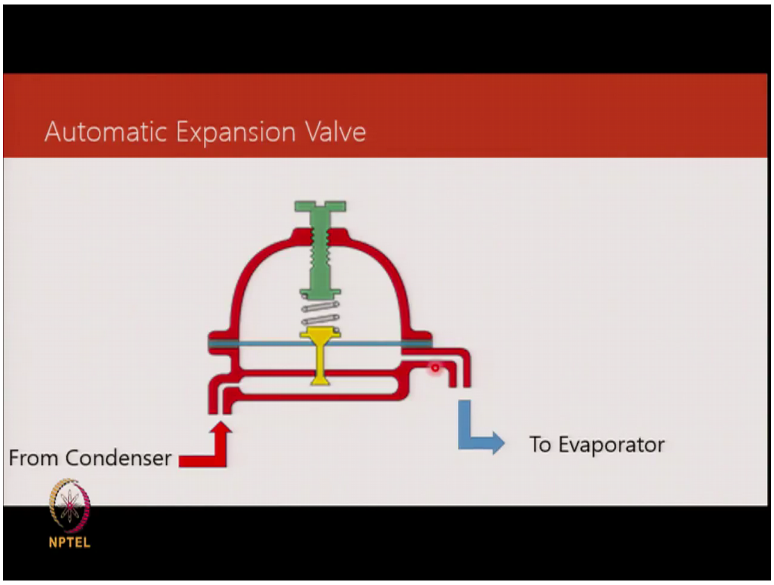

Then, we have an automatic expansion valve. You know automatic expansion valve, the intention is to keep the evaporator pressure constant. So, how do you accomplish that? So, we have fluid coming from the condenser, it has sub cooled liquid, it gets into this zone and then, we wanted to pass through the throttling device. The difference between the manual throttling device that we saw in the previous slide where it is fixed once you have adjusted the stem and this one is that there is an active element, there is a diaphragm.

So, this is our disc typically a stainless steel disc which is flexible like a bellow. It would move up and down based on the spring pressure which is coming on from the top and the pressure of refrigerant coming from the evaporator. So, let us take a scenario. When the pressure goes low, the spring force is constant. So, if the spring force is constant in the pressure from the evaporator goes low, what is likely to happen is that there will be movement downward.

So, the conical section that you see here, this will have a larger opening. So, a wider flow is happening. So, when the pressure goes lower, there is more refrigerant flowing in. So, the pressure will rise and similarly, if the pressure were to be too high, then this would push the diaphragm upwards closing it. So, less refrigerant is flowing in and therefore, the pressure will reduce. So, this is an active adjusting device which is throttling, but with an intent to keep the pressure in the evaporator constant and you would need such a device when you want a constant evaporating temperature because that saturation these two are related. So, if you are targeting a constant evaporating temperature, you would do this. This is not the most commonly used expansion device. So, now what we are going to get to next is a thermostatic expansion valve.

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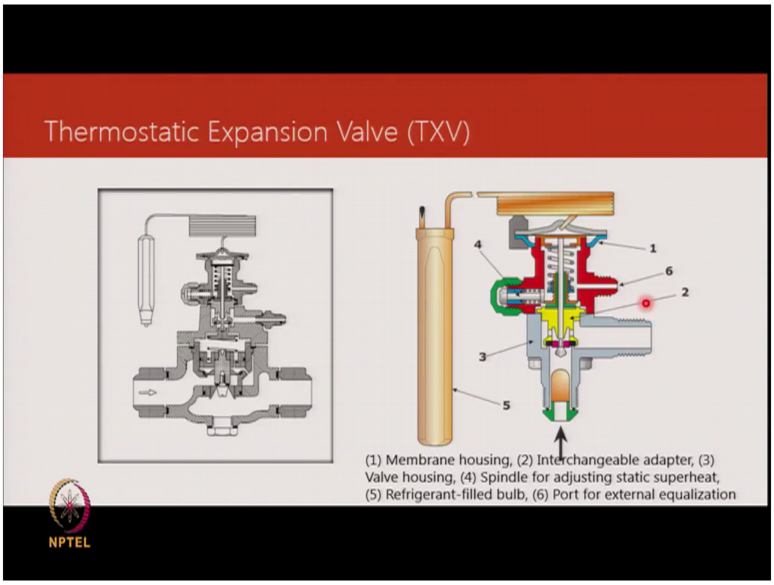

So, here on the left you can see a cross-section of a particular type of expansion valve where there is a straight connection. So, refrigerant comes from the left and leaves from the right. It is the straight through and on the right is a picture of an angle connector expansion valve, where the refrigerant comes in from the bottom and leaves it horizontally. There are some parts of this expansion valve which we can use the figure to. So, there is first of all the membrane housing. So, this diaphragm that moves continuously up and down in the expansion automatic expansion valve, there is a similar component in the thermostatic expansion valve also.

So, over here and the body, this is housing, it is the membrane housing. So, in many expansion valve designs, it is possible to remove this and use another one depending on what refrigerant you are using and there are other manufacturers who would combine this welded for reasons of preventing refrigerant leak and that is also an accepted design.

Then, what do we have next is an interchangeable adapter. So, for reasons of reducing the number of parts and having one body for multiple capacity applications, it is possible to change the orifice where the expansion happens and then, the flow rate properties of the refrigerant will change. So, this is another part which is an increase of an intricate part of the expansion valve.

Then, we have a spindle which is part number 4 or before that yeah 3 is the housing. So, the body of the valve is part number 3 and part number 4 is an adjustment for static superheat. So, the spring force can be altered when we are optimizing the system. So, you move it counter clockwise and counter clockwise, we will be either compressing the spring or relaxing it and with that the spring force on the diaphragm will change and then, we have a refrigerant filled bulb.

So, this is a key departure from the automatic expansion valve. In the automatic expansion valve, the variable we were looking at was pressure. So, we wanted constant pressure in the evaporator, so that we have a constant evaporating temperature against which we can have heat exchange. Here we are replacing that with a bulb. So, from a pressure from monitoring pressure, we are looking at monitoring temperature using a bulb which is filled with the refrigerant and usually the refrigerant is not the same as what is used in the system because of reasons that we are going to get into later, but we want a temperature signal to be modulating the diaphragm, so that we can control the superheat at the outlet of the evaporator or inlet of the compressor.

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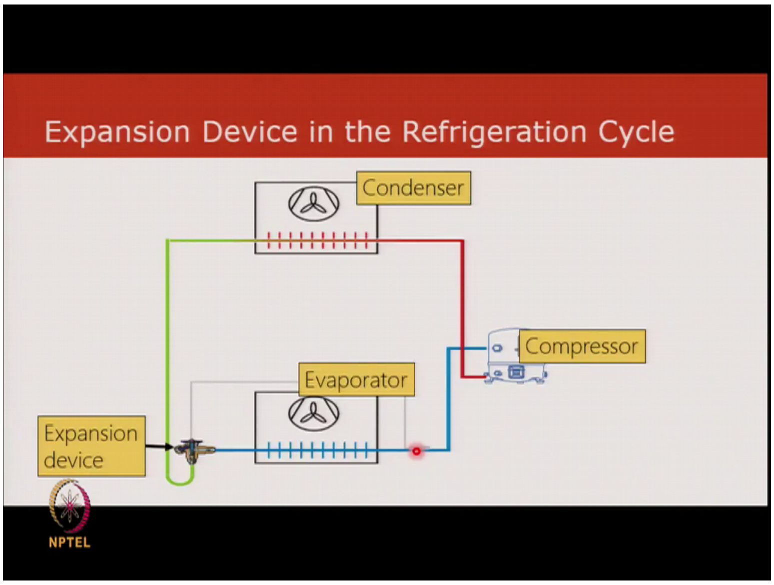

Now, here we can see an expansion device in the refrigeration cycle. This is a very simple refrigeration cycle where there is no distributor. Now, for those of you who are wondering about what a distributor is, there is another element which comes between the expansion valve and the evaporator for large systems. So, if we have 5 ton or 7 and half ton evaporator like a packaged unit an air conditioner, we would have multiple circuits feeding the evaporator. So, the refrigerant enters the distributor as a tube like as liquid you know a typical half inch diameter tube and then, there are smaller tubes maybe one-fourth of an inch or 3 by 16th of an inch that leaves the distributor feeding individual circuits in the evaporator.

We do not have to remember all of this right now because when we look at heat exchanger design, we will look at a circuiting and optimizing it, but I want to mention that this is a simplistic representation of most systems where an expansion valve was used. We would have a distributor which will distribute refrigerant to different circuits in the evaporator and then, here you can see the bulb. It is going across the evaporator and it is on the suction line leaving the evaporator connecting to the compressor. This is where we have got a sense temperature.

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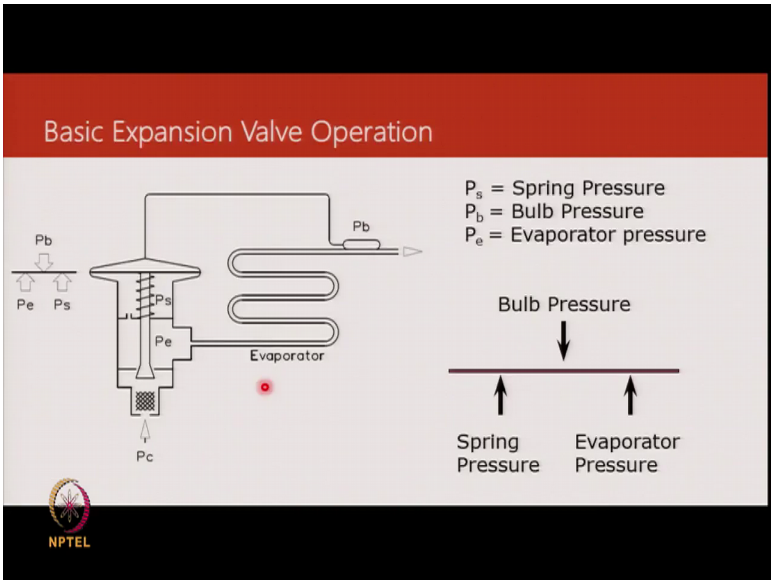

So, how do we convert temperature into a modulating signal is we put this bulb which is filled with refrigerant in contact with the pipe. So, there is good thermal contact or of conduction whatever is the temperature of refrigerant in the suction tube, it would be a good assumption that will be the temperature of the fluid inside this bulb and varying temperature would lead to varying pressures in the entire system which began from the bulb and goes right up to the top of the diaphragm here, right. Now, here what is going to happen is we have an evaporator. So, we have the evaporator, the pressure of refrigerant in the evaporator which is acting on the lower part of the diaphragm, we represent that by P e evaporator, right.

So, that pressure and the pressure coming from the bulb P b for those of you who are not able to read what is written here is P b. The pressure inside the bulb and then, we have a force or spring force which is translated into a pressure term P s which is dependent on where we have adjusted it or if you have not adjusted, then an expansion valve will be shipped whether fixed setting.

So, based on the bulb pressure, spring pressure and evaporator pressure, we will define the degree of opening of this orifice and for that reason there this is a continuously adjusting expansion valve and it is a thermostatic expansion valve, not an automatic expansion valve because we are sensing temperature and then, converting it into a pressure signal. So, this is one of the most commonly used expansion devices for larger systems, where the compressor size increases. We are really concerned about a compressor safety. We do not want any refrigerant getting into the compressor shocks or suction and once we put this in, we are sure that it will continuously keep varying. No matter what happens to the evaporator load or other system conditions, we will have a reliable operation.

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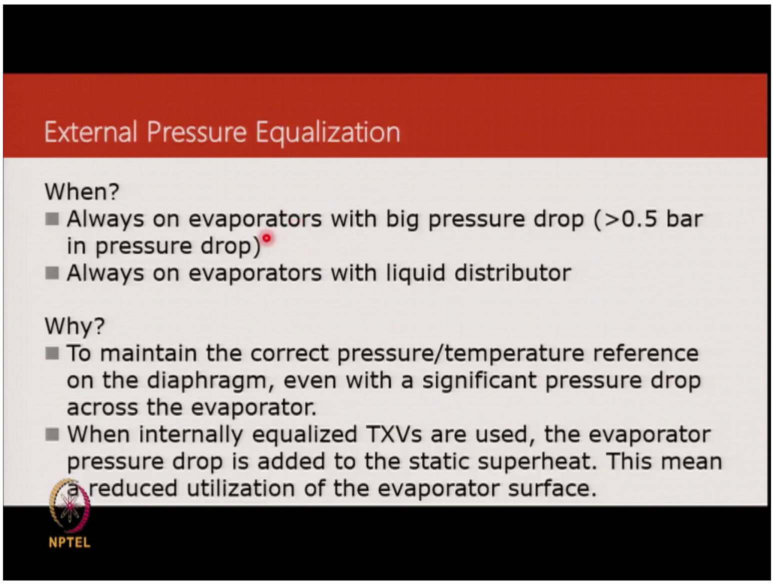

Then, we have another expansion valve category which is thermostatic expansion valve with external pressure equalization. So, if you see this simple system, we have connected the evaporator pressure directly and we do not seem to recognize any pressure drop in the evaporator. We kind of assumed that the pressure here and the pressure here is almost the same which will be true for some systems which are simple systems and therefore, using an internally equalized expansion valve is fine, but when there is a large pressure drop and there are evaporators which have a liquid distributor you mentioned before, then the pressure drop is significant for us to move to an externally equalized expansion valve.

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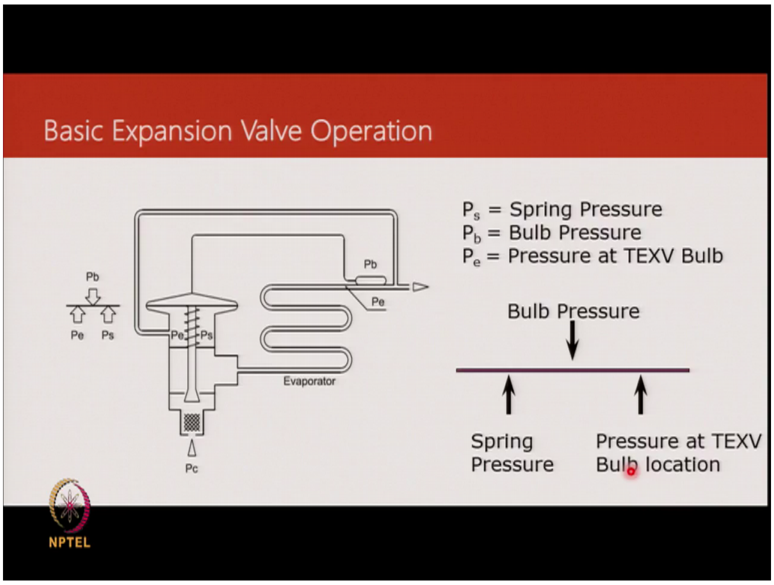

So, what happens in an externally equalized thermostatic expansion valve is instead of using this pressure from the evaporator, act on the lower surface of the diaphragm we put in another tube. So, this is a copper tube which would connect the point at which we place the thermostatic expansion valve bulb to the lower end of the diaphragm. So, here what has changed is the bulk, pressure remains the same, the spring pressure remains the same and we have pressure at the thermostatic expansion valve bulb location. So, it is more accurately representing saturation conditions at the evaporator outlet or more correctly said at the point at which we are sensing the bulb.

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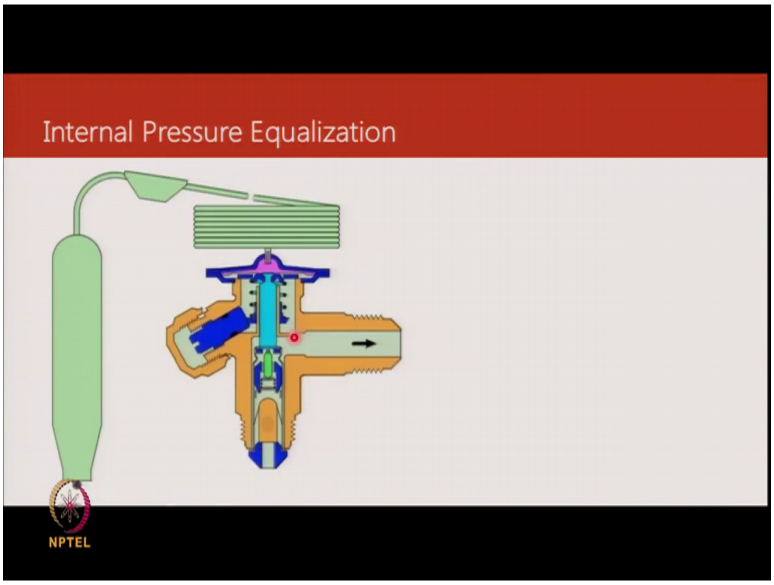

So, this is a little more detail on the construction. The cross-section of the internally pressure equalized expansion valve as you can see it simple the hole for equalization is right inside. So, we do not really need to worry about any tubes and in case of an external pressure equalization, there is a port.

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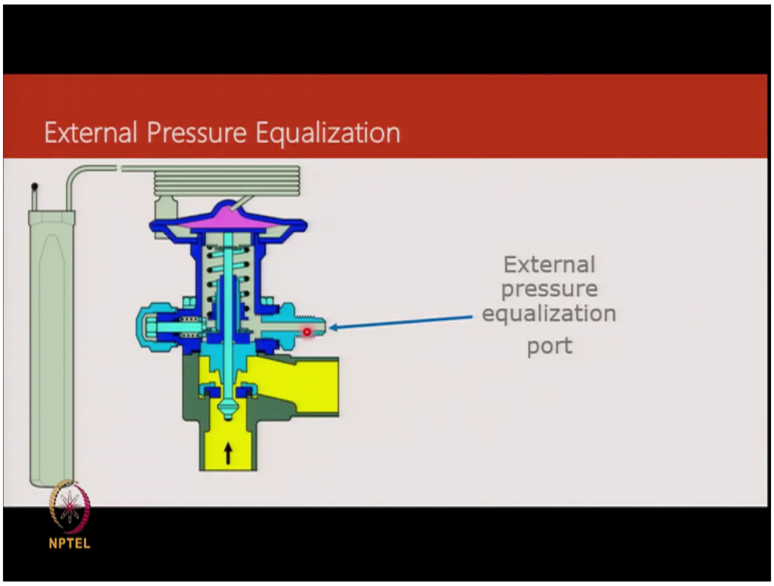

So, in addition to the liquid line which enters from the bottom and the suction line leaving horizontally, there would be another tube, a copper tube which will connect the port.

So, we will need some adapters. This is a threaded connection. Now, we could also have a soldered connection and those are other variants of expansion valves when you are designing a system as to how we want to connect it. When you are looking at airtight systems, we look at reliable systems where there is no need for replacement then we would look for soldered connections for all these parts here. When we feel there would be likely a need for making changes, then we would look at threaded connectors.

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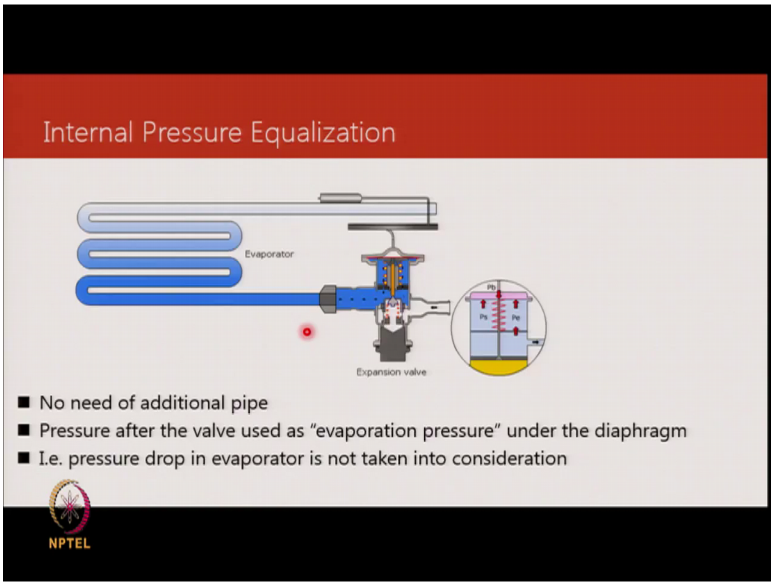

What are the advantages of internal pressure equalization is that there is no additional piping needed. So, it is a simplest system pressure after the valve is used at evaporative pressure under the diaphragm which we will discuss and the pressure drop is not taken into consideration which means it is negligible or we are adjusting it using the spring force if it is constant.

This we would do when using distributors. We more or less covered this and the whole idea here is that if the pressure drop in the evaporator is more than 1 degree kelvin, so we seen pressure drop and 1 degree kelvin means you looking at saturation conditions. So, then we would use a externally equalized expansion valve.

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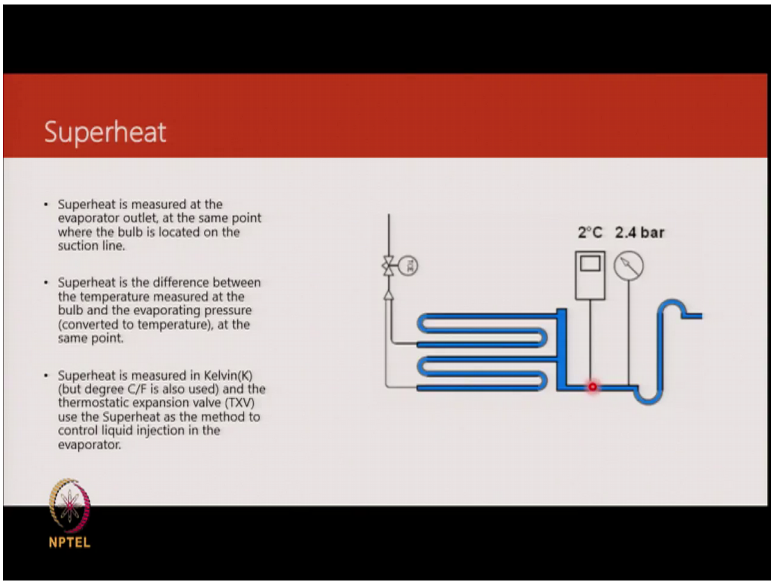

Super heat we would discuss the theory, but if you were to look at measuring it in a system, then this is what we would do; possible to read, right? Not easy. So, super heat is measured at the evaporator outlet at the same point where the bulb is located on the suction line. So, if you are looking at verifying the performance of a thermostatic expansion valve, we would do this. We would tap the suction line which means you would intrude into a system, we would take a pressure reading and we would take a temperature reading.

So, if these were the two readings taken, then we would convert the pressure to its corresponding saturation state and then, the difference between the real temperature and the corresponding saturation temperature will give us the superheat and as we discussed before, the key purpose of maintaining a superheat is to prevent liquid refrigerant getting into the compressor.

Now, in some cases where we would not want to puncture the system and we want to still get a reasonable estimate of the superheat, we could do this. We could take the temperature somewhere in the middle of the evaporator where there is a two phase phenomena happening which means the evaporation is happening. So, we can directly take that and by doing so, we are assuming the pressure drop from that point to the suction is not significant.

So, we would take this temperature and you take this temperature and the difference between the two would give us a fairly good idea of what the superheat is. This is an alternative way. Now, where can we run into trouble if the flow rate now this is a distributor here. So, this is feeding one circuit, the refrigerant flows and then, gets to the header and then, there is another circuit, again refrigerant comes in and goes to the end.

If the refrigerant flow and both these circuits was not equal and we end up taking temperature here, then we could be running an assumption which is not really valid. So, we could get to a superheat value here, but in reality there could be liquid flowing to the compressor because the other circuit is feeding more refrigerant and we are not factored that part. So, the most accurate way to determine superheat would be this; we have taken the pressure and temperature at the point of interest.

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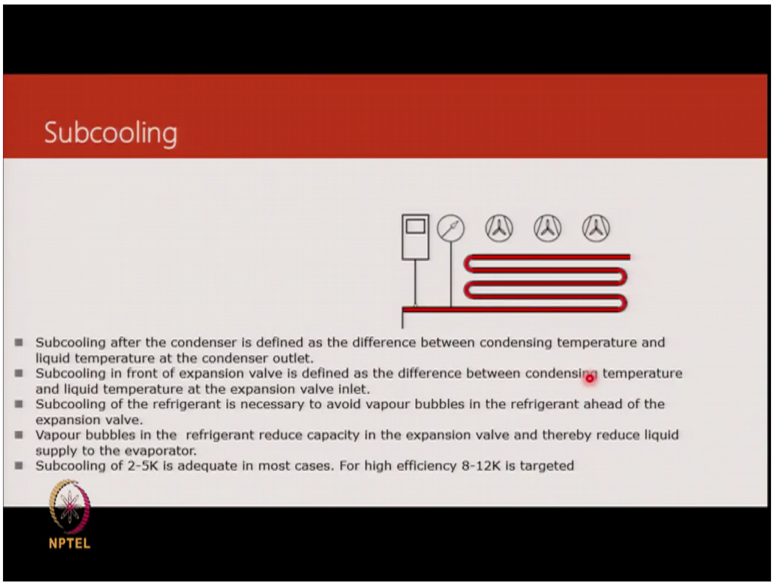

Then, again we looked at subcooling theoretically. Now, if you are looking at our system maybe want to measure the subcooling, we would do something very similar. We would take pressures and temperatures and the extent to which the temperature at the point we measure the temperature, the condenser outlet is below the saturation temperature that was the sub cooling. We would do these measurements during system design because you want to guarantee liquid going to the expansion devices in liquid state, sub cooled state and that is reasons of performance.

Then, someone asked a question before were vapor bubbles in the refrigerant reduce the capacity and thereby reduce liquid supply to the evaporator and therefore, the capacity of the system. So, that is the reason we are attempting to keep it sub cooled and typical numbers 2 to 5 degrees kelvin. If you looking at highly efficient systems, then we could take this to 12 degrees, even 15 degrees and that depends on the appetite for cost and what efficiency numbers we are targeting.

The other part about subcooling which we need to be careful about is even assuming pure substances. So, pure substances means there is no glide effect. When we look at a certain saturation condition, then there is a direct correlation between temperature pressure, but in refrigerants which are mixtures of two substances, there is a glide and that glide leads to some errors. So, we just need to be aware of that.

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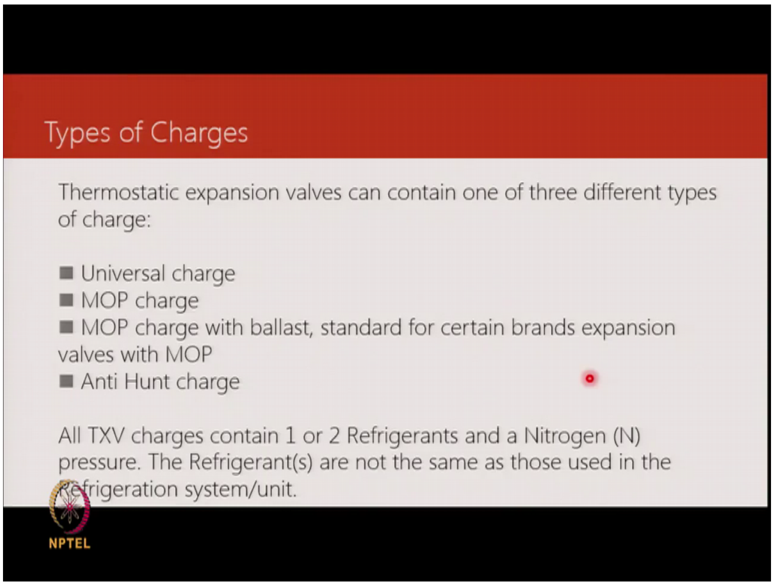

Then, I mentioned about the substance that is in the bulk being different from the refrigerant itself. So, there are different classifications of charges inside the thermostatic expansion valve. So, there is a universal charge, there is MOP charge and then, there is MOP charged with ballast which is for certain brands you know it compensates for expansion and then, there is an anti-haunt charge which is meant for systems where there is high instability.

So, the response time is adjusted in a way that the valve is not continually adjusting to varying load conditions. The most refrigerant most of the expansion valves would have in the bulb, a combination of at least two refrigerants and nitrogen and the refrigerants not being the same as the system refrigerant.

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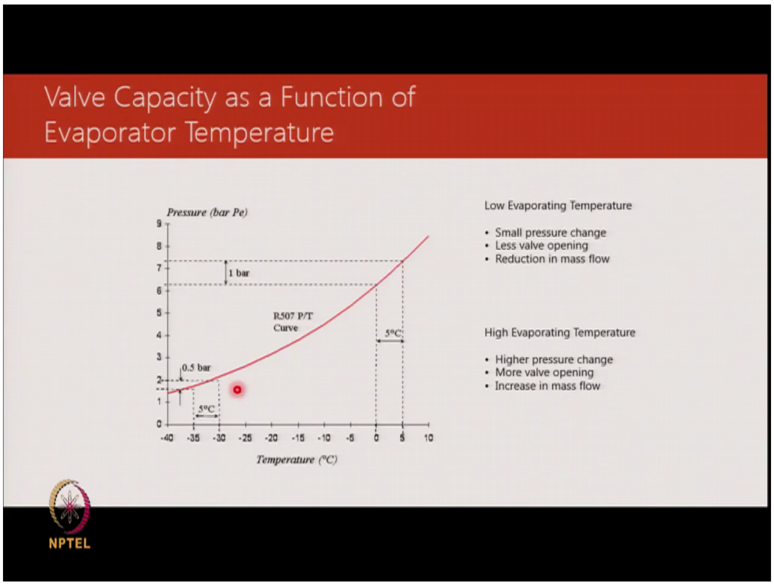

Now, we look at the behavior of the expansion valve in response to evaporator temperature. So, low evaporating temperature means small pressure changes less valve opening and a small reduction in a mass flow whereas, at high evaporating temperatures, there is a high pressure change and there is more valve opening which means there is an increase in the mass flow rate.

So, if you look at the change, a similar change for 5 degrees change in temperature, there is a pressure difference of 1 bar required at high pressures whereas, at low pressures that is just 0.5 bar. So, this is the characteristic curve which is relating the pressure in the evaporator to the temperature for a typical expansion valve, how it is constraining the refrigerant flow.

Now, some of this is stuff which you need to look at when you are looking at advanced design optimization techniques. So, it is there for you to know that there is a valve capacity which varies with evaporator temperature. The valve capacity will not be the same at two different evaporating temperatures. The same valve will allow for different performance curves. Then, we look at the cross charge.

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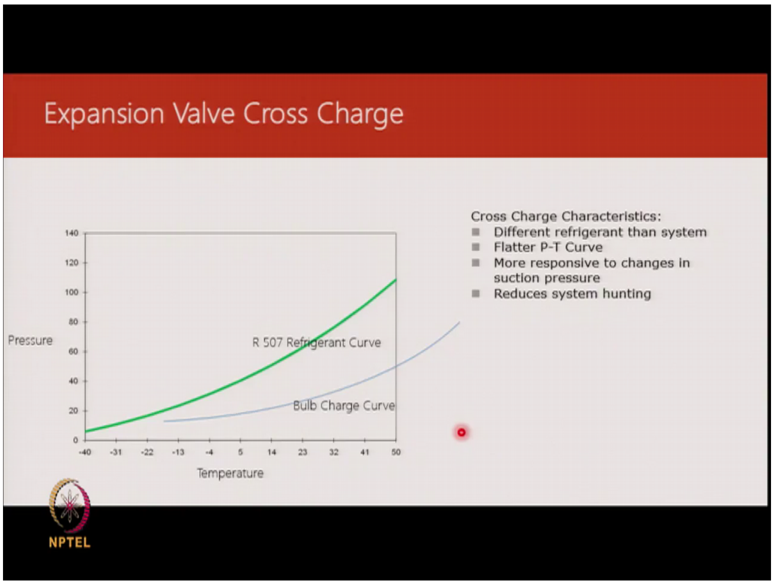

So, an expansion valve has a substance in the bulb which is different and what it really means is that the pressure temperature curve can be made flatter, so that it is more responsive to changes in suction pressure and it reduces hunting of the system. So, one way to relate to hunting is when we looked at this feedback going from the evaporator outlet to the expansion valve, the diaphragm is moving. If that diaphragm movement was too often, it would become a system which would adjust too fast.

So, we have choking one stage and then, we have a full opening and then, again choking. So, there will be a variation in pressures and temperatures and that is what is called hunting which is undesirable in the system because it prevents steady state operation. So, you are pulling in that constant, your components are unduly stressed because of these variations in pressure.

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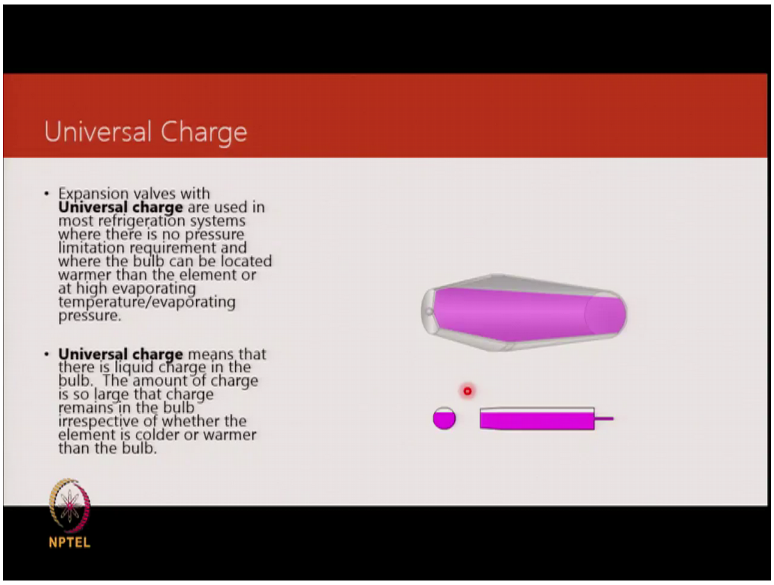

Now, the universal charge expansion were used in systems where there is no pressure limitation requirement.

Now, pressure limitation requirement is let us say we talk about a refrigeration system, we maintaining a temperature of minus 25. The average temperature is minus 30 and such a system when it is switched off, what is likely to happen the refrigerant would come closer to the temperatures in the ambient and when we start the compressor, there could be a possibility of an overload. So, there is a need to control the refrigerant flow using expansion valve in a manner that we do not overload the compressor in systems designed for low temp applications.

Not all systems have those limitations. So, if you talk about a packet system which is used or a chiller system for comfort, they are not normally encountering that limitation and for those applications, simpler applications, we use a universal charge. The amount of charge that remains in the bulb is irrespective of whether the element is colder or warmer state. See if you look at an externally equalized some static expansion valve, there is fluid inside this bulb and there is a diaphragm.

If the temperature here is higher, they could be migration of the refrigerant from the bulb to the diaphragm and in certain conditions if all the fluid were to move out from the bulb to the space above the diaphragm, then there would be nothing to sense what is happening to the temperature at the suction line. So, there are valves where it is specified that the bulb has to be in a place which is cooler than the diaphragm body. So, when designing system, we would keep the expansion valve body location in a warm area which means the refrigerant is always in the bulb.

The substance that is used for sensing temperature is always involved, then universal charge the charge quantity is so high that no matter what happens, there will be always certain amount of a liquid in the bulb and therefore, it will continue to sense and therefore, it is relatively robust in terms of application. We are not constraining the engineer to ensure that the temperature is lower or higher and then, we have MOP charge.

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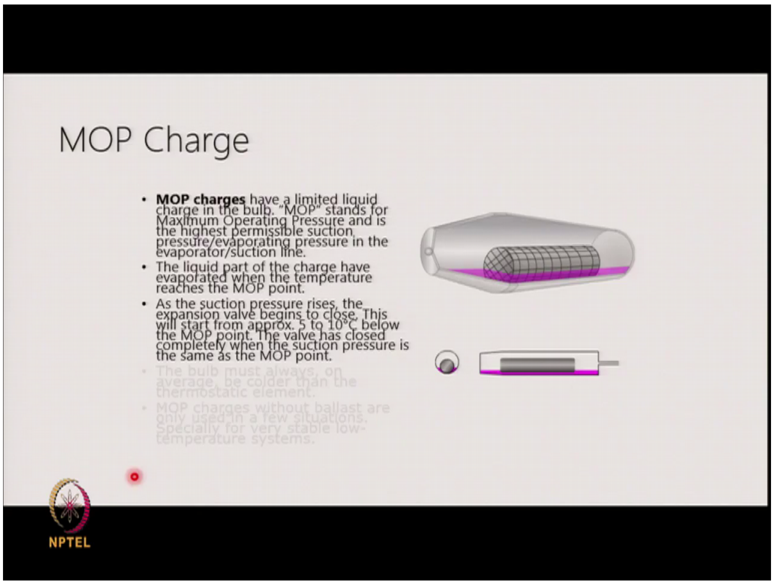

So, MOP stands for Max Operating Pressure and what we do in max operating pressure situation is that we will cause the refrigerant inside the substance. More accurate term is the substance inside the bulb to vaporize completely at a certain temperature, so that it does not open the valve any further. So, that is to limit the suction pressure at which the system will operate. So, now these will be used typically on factory made units where suction pressure limitation on starting is required for example in transport sector.

So, let us say there is a refrigerated truck and it has been kept empty for a few days and then, suddenly it is loaded with the fish which has to be transported at low temp. So, the expansion valve will tend to feed maximum refrigerant in the beginning and that is not what the compressor has been designed for. It has been designed to maintain the system at a certain point.

So, take care of that transition when the compressor is started, we will have MOP limit, the quantity of refrigerant flowing in there.

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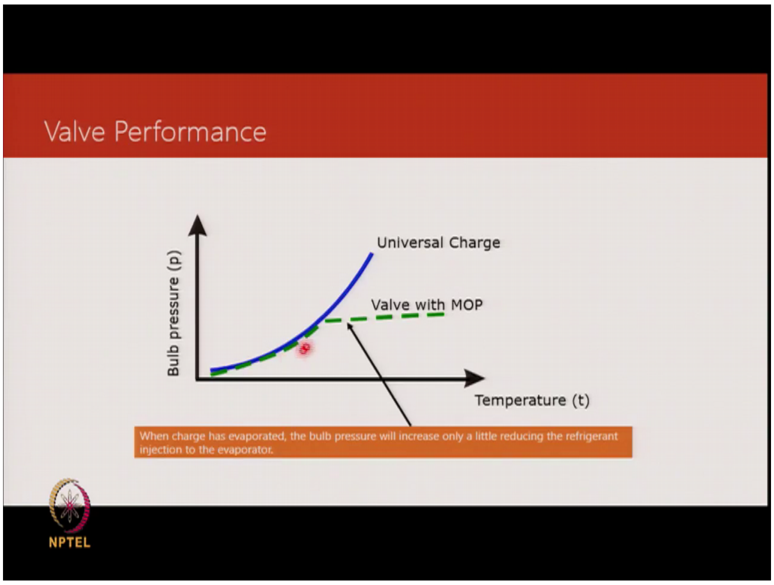

If there is a universal charge and as the temperature rises, the flow will increase whereas, a valve with MOP does predefined design point. It will just flatten out and the bulk pressure then does not increase which means there is no further opening of the thermostatic expansion valve.

We have the highest risk of charge migration in MOP valve because we have limited the substance in a way that all of it will evaporate at a certain condition and there will be nothing left to further increase the pressure in response to increased suction line temperature. So, what we are saying is that we will allow the superheat arise, but we will not feed additional refrigerant. Since we reduced that quantity, there is a risk of migration which is highest in case of MOP charge inside that sensing bulb and to address that, then comes another design innovation you can say where we put in a ballast in which the fluid is not really free to migrate.

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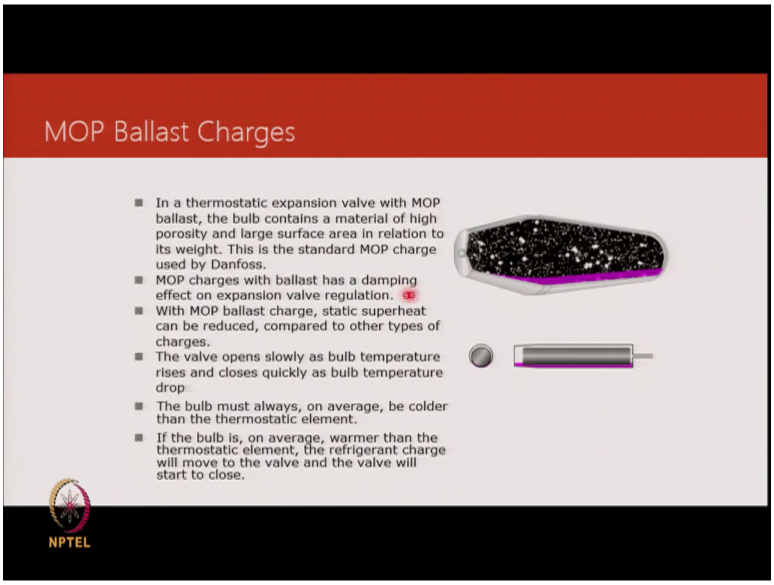

So, what MOP charge with the ballast does is, it has a damping effect on expansion valve regulation and then, one of the companies that I worked for, it uses this as a standard MOP charge. The valve opens slowly as bulb temperature rises; closes quickly as bulb temperatures drop. The bulb must always on average be colder than the thermostatic element and the refrigerant charge will move to the valve and on an average, it will form better.

Now, these valves with MOP ballast would become useful in certain unique heat exchangers which are called multi channel heat exchangers and then, brace plate heat exchangers. So, in brace plate heat exchangers, we are having heat transfer occur between two parallel streams of water and refrigerant and there is a high degree of responsiveness required because the refrigerant volumes are really small. The system is small and compact and if we do not have the adjustment quickly, then we will have big challenges to reliable operation of the compressor.

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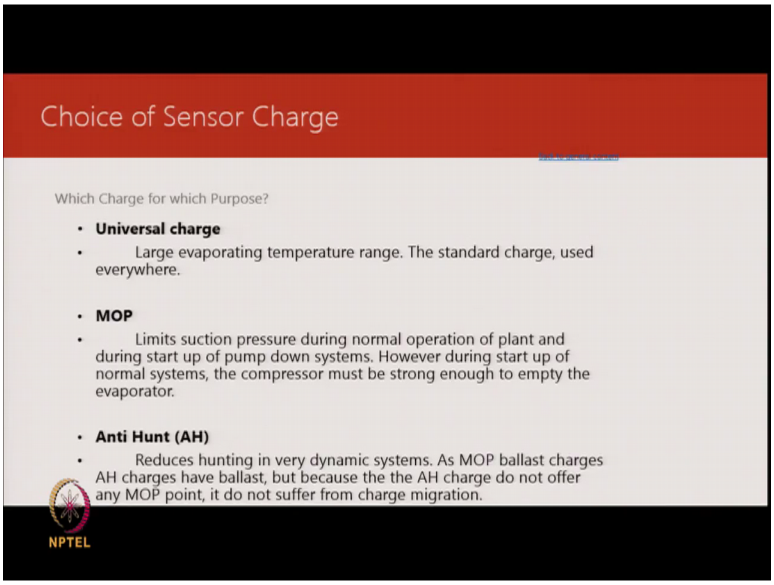

So, if you look at a summary of the different type of a charges that are available in an expansion valve, then this would be oh you know universal charge would be for addressing a wide temperature range where there is no need to constrain the operating pressure.

MOP is where suction pressure during normal operation, but during the startup of normal system, the compressor must be strong enough to empty the compressor. So, basically what I said before is a much more accurate description that if you want to limit the suction pressure during startup, then MOP would be the best choice and anti-hunt valves would have a charge which would address dynamic scenarios much better. So, it would compensate any kind of hunting characteristics of the system.

So, it is basically a delayed response. You have tuned the response in a way that you do not allow hunting to happen.

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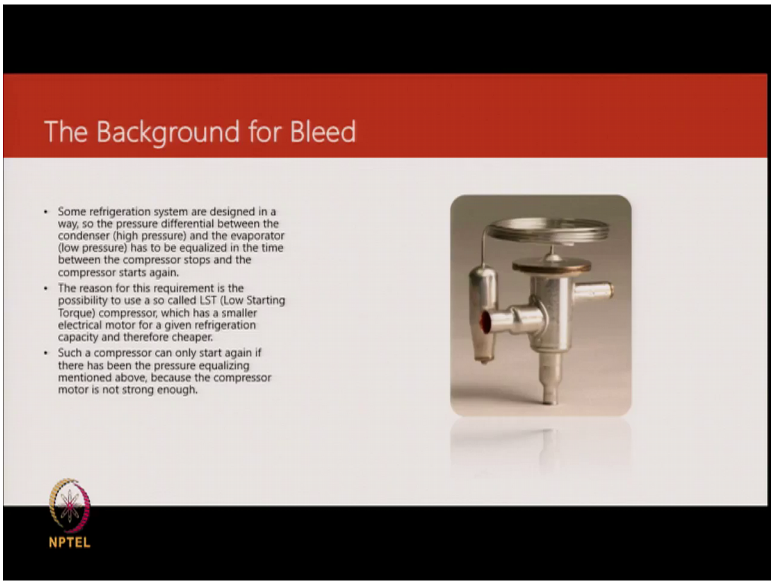

Then, there is another aspect of expansion valve which we must be aware of, but what happens is when a system is stopped in an expansion valve, we could keep the high pressure and the low pressure zones airtight from each other or like pressure tight from each other which means, we stop the system. If the discharge pressure was 300 psi, it stays there. If suction was 77, it stays there until the compressor is required to restart.

Now, a number of compressors have limitations on torque when they start and they would not be able to start if the pressures are not equalized across the suction and discharge. So, the need arose to consider some means of causing a small leak of the refrigerant, so that in the off-cycle, both sides the suction in the discharge come to the common pressure and then, the starting torque requirement is reduced. So, that is the accomplished by providing an expansion valve which has a bleed.

Yeah another thing to remember is in capillary systems. There is naturally bleed happening because there is no adjustment, there is nothing. Whatever we designed for is available for pressures to equalize and all residential systems refrigerators, they equalize through the capillary. It is only in expansion valves where we are controlling the orifice opening that there is a need to look at this aspect.

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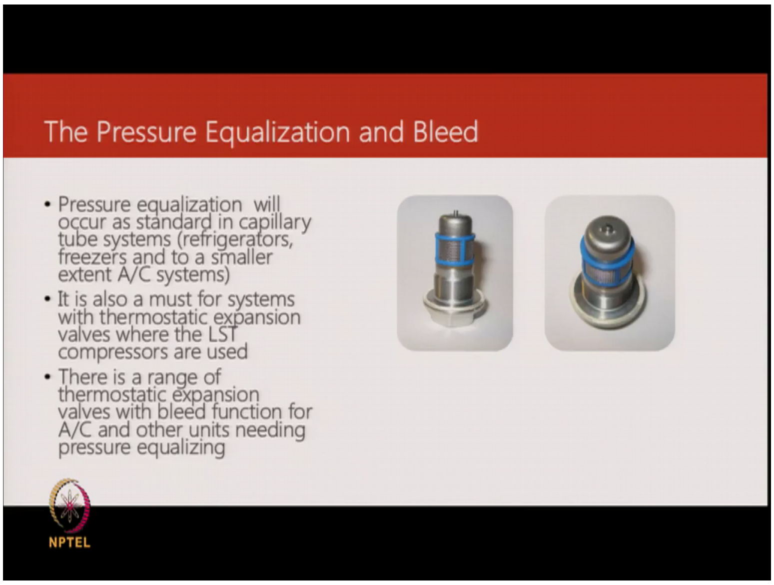

So, this is what devices with a bleed will look like.

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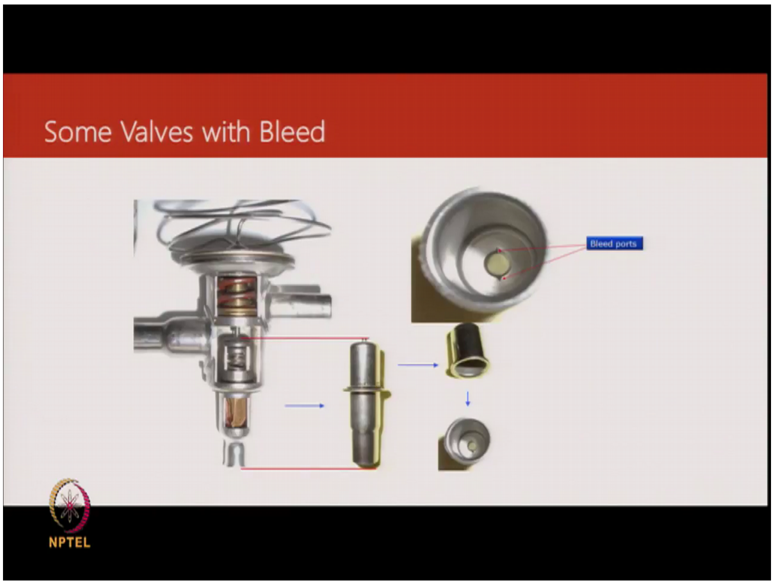

So, instead of allowing for a pressure tight C, you provide a small blue on the edges here. So, these two are the bleed ports. So, instead of allowing the seal which is pressure tight, there is a small groove provided which will allow for refrigerant to leak and typical off cycles for a compressor could be 5 minutes, 3 to 5 minutes and the cycle times could be very different if the load conditions are different. So, you could have off times even longer. So, then you are designing a system if in 3 minutes, you are able to equalize, it is perfect.

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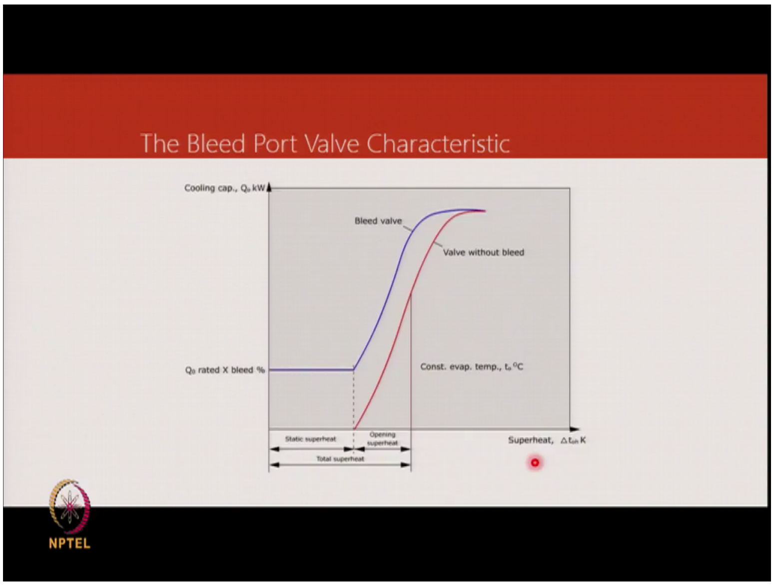

Now, what happens with the bleed port valve is in addition to the flow that happens through the regular opening, there is a small amount of a refrigerant flow that will happen through the bleed port. So, in order to compensate for that in our estimates calculations and normally the designer does not need to worry about it because it is already factor in the selection parameters that we will use for expansion valves.

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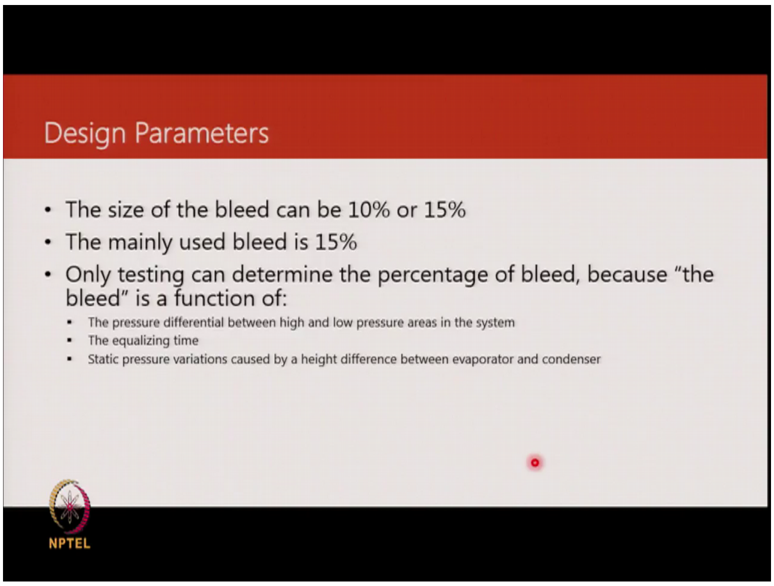

Then, in terms of design parameters, the size of the bleed can be 10 percent or 15 percent of the total refrigerant flow that we have size the expansion valve for and there is no thumb rule except doing a test to find out what percentage bleed would be sufficient. So, this is a part of the rigor of proving system performance during reliability testing that we have addressed this comfortably and there is no issue.

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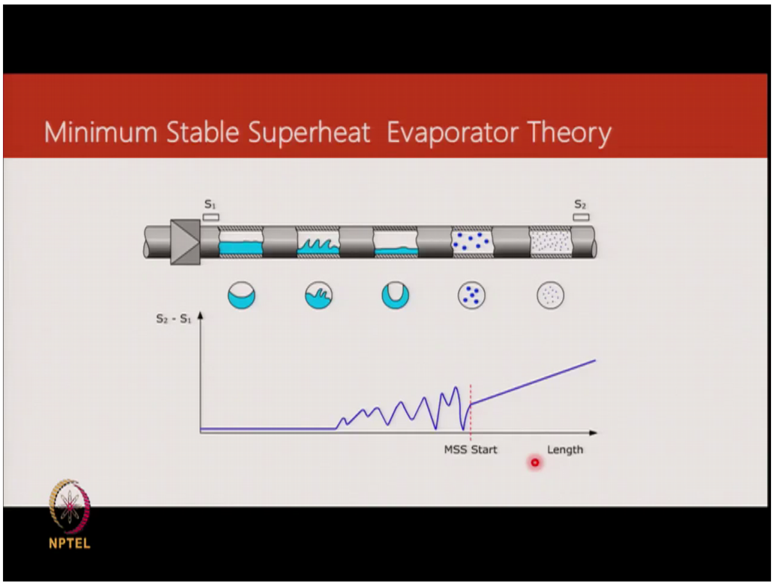

Then, we come to a slightly more interesting part of an expansion valve which is what is the minimum stable superheat and there is some theory or background to what is minimum stable superheat. So, what you see in this slide is the refrigerant which is a mixture of vapor and liquid which is progressively moving into a different types of flow which could be slug, mist, etc till in the end there is superheated vapor.

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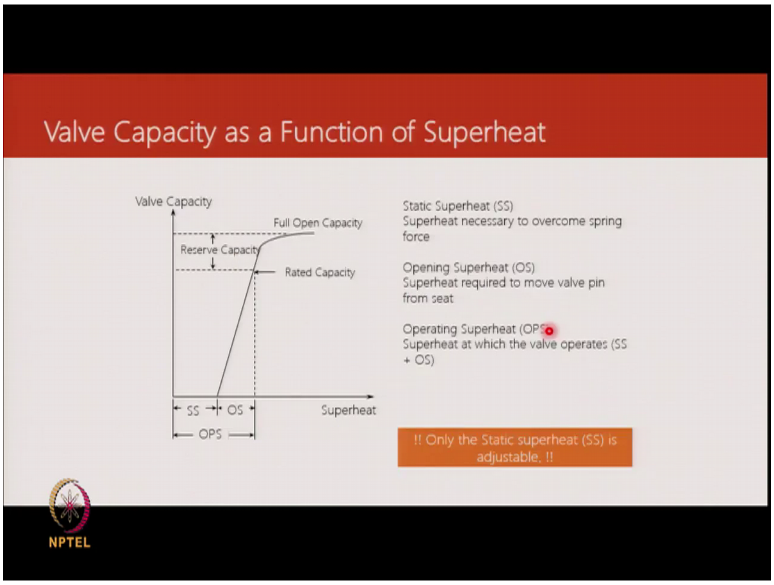

Now, valve capacity is a function of superheat. So, the higher the superheat, the more will be the valve capacity because we are adjusting it in response to superheat, right. Now, in a valve there is a certain spring force. So, there is a static superheat. So, static superheat you can remember as something which is directly correlated to the spring force. We were just at a certain setting and that is what we have and then, there is a part in which there is an operating superheat which is super heat required to move the valve pen from its closed position to its fully open position if we add the two static superheat and operating superheat and that is the entire performance area of the valve.

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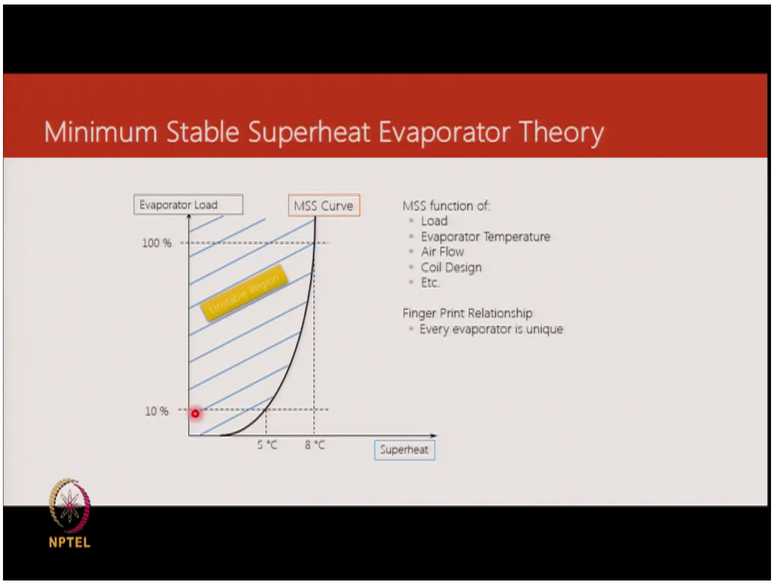

Here we come to the minimum stable superheat theory. So, the minimum stable superheat is a function of the load, the evaporator temperature, the airflow coil design and a whole lot of evaporator design parameters. The point we need to understand here is we looked at compressor and we find that the expansion valve depends on the compressor in terms of sizing.

Similarly, the superheat parameter that we use for the evaporator depends on the evaporator design. So, we have not touched heat exchangers yet, but the kind of airflow in the evaporator will determine what kind of stable superheat we can operate it and the intention behind having the minimum stable superheat is to keep the discharge gas temperature as low as possible.

So, we have superheat which we need to prevent any liquid getting into the compressor, but we do not want excessive superheat because then we will end up de superheating in to large area of the condenser and we will lose out on the effectiveness of the condenser. Are you with me on this? Why do we have a discussion around minimum stable superheat? It is a parameter that impacts cost, it impacts our ability to optimize the heat exchanger and the system together and then, every evaporator will have its own unique minimum stable superheat because of the design criteria, how many circuits it has which circuit is loaded, how the airflow pattern is there and all that.

So, here we are now crossing into the zone that when we look at one component, we are also having to look at an overlap with parameters of another component. So, if we keep the superheat too small, we would what happens is that we looked at that example of two circuits. So, one circuit is feeding a small quantity of liquid refrigerant and another circuit is feeding vapor and the two are getting mixed up. So, the expansion valve opens in response to droplets coming in from one circuit and then, it responds to vapor because there will be a continuous movement up and down of the diaphragm and therefore, throttling and then, we will want to adjust it higher.

So, as we adjust it for the circuit which is least loaded, we will starve refrigerant in a good part of the other circuit. So, that is why this mention of fingerprinting of every evaporator. So, when we start optimizing, we want every circuit in the evaporator to be almost equally loaded and then, we strike a compromise that fine we could do so much and we cannot go beyond this. We cannot be making the perfect evaporator. So, we will tolerate a certain part of the operating superheat to allow for stable operation and I think all the parameters are mentioned here. I have already discussed with you. So, that kind of pretty much it covers this part of, this I am skipping.

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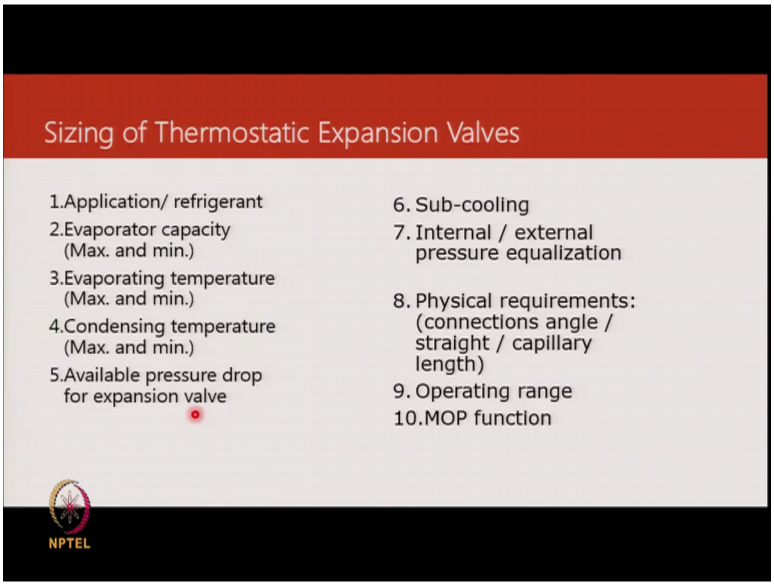

So, here we come to a certain summary what we covered so far. So, we looked at application, we looked at refrigerants, we looked at, we did not looked at evaporator capacity maximum minimum yet, but when we do the expansion valve sizing, we will need to look at that.

So, right now we talked about the evaporating, the operating and look for the compressor. So, implicit in that is the minimum maximum cooling capacity that we are considering and we will need that when we are selecting the expansion valve and as you see more and more, we get into parameters for selection. Whatever was needed for the compressor selection is equally relevant for the expansion valve except that we are dealing with some new terminologies like thermostatic expansion valve with the minimum stable superheat. We are looking at some circuiting details and all that, but the core parameters that we derived from the pressure enthalpy diagram remain the same and are equally relevant for both the expansion valve and the compressor.

Now, another simple way to look at expansion valve selection is to use whatever engineering tools are available to define the pressure drop that happens across the expansion valve because it is an orifice and then, we look at what would be the minimum pressure drop and at that minimum pressure drop, what is the maximum flow rate of refrigerant that we need and then, we look at the maximum pressure drop and at that what are the two minimum and maximum flow rates that we can accept. Once we have done that, then the thermostatic expansion valve will operate pretty effectively because you address the extremes.

So, all the region in between will work this. That is one approach to selecting an expansion valve very effectively, then we have covered sub cooling, how to measure it as well as the theoretical aspect of how it impacts energy efficiency, the net refrigeration effect, then we have looked at a physical requirements, I touched upon it very briefly like the solder angle and straight, but those are things that when you begin to build a physical system, you will have the liquid, leave the condenser in a particular orientation, you will want to feed it to a distributor orientation and then, you will make your decision about whether to use a straight through on an angle expansion valve. It is most commonly used expansion rather than angle expansion valves because the need to divert refrigerant flow it is handy to have something which has refrigerant come out from the evaporator horizontally and then, go vertically down or vertically up, sorry condenser. So, from the condenser you come to the distributor and then, this whole part happens. So, you normally feeding from the expansion valve toward distributor and having that angular configuration is useful.

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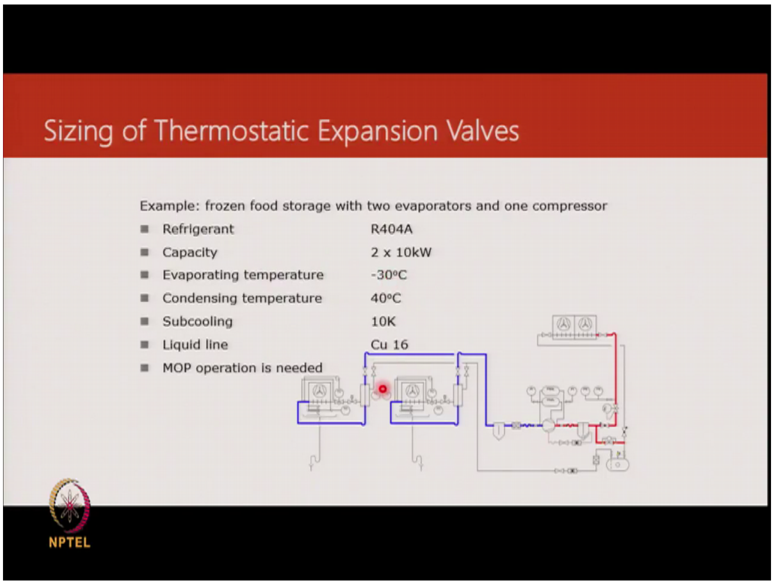

If you look at an example of a frozen food storage with two evaporators and one compressor and a refrigerant 404A, then we will typically have something like this for selection. We will have the capacity. So, if there are two evaporators, 2 into 10 kilowatts evaporating temperature condensing temperature, sub cooling liquid line size and then, whether or not MOP is required. So, since this is a evaporating temperature application of minus 30, we will end up making use of MOP valve.

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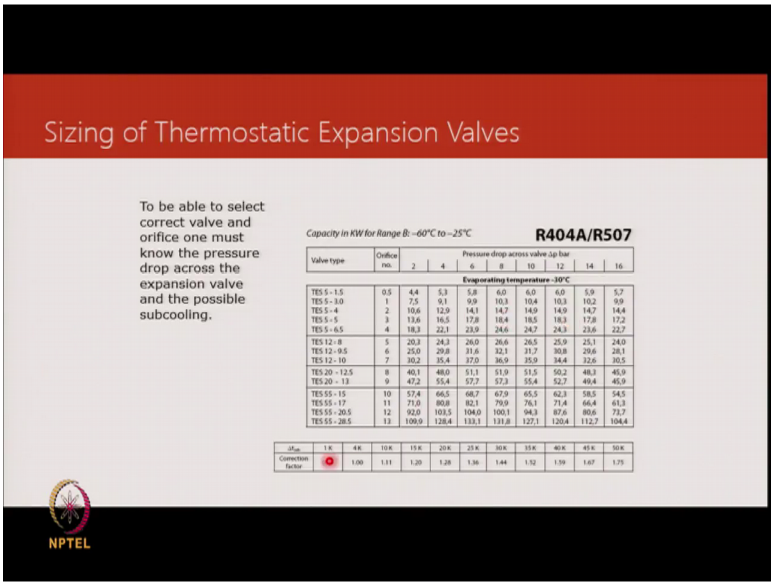

Valve type	Orifice no.	Pressure drop across valve Δp bar 2	4	6	8	10	12	14	16
		Evaporating temperature -30°C							
TES 5 - 1.5	0.5	4,4	5,3	5,8	6,0	6,0	6,0	5,9	5,7
TES 5 - 3.0	1	7,5	9,1	9,9	10,3	10,4	10,3	10,2	9,9
TES 5 - 4	2	10,6	12,9	14,1	14,7	14,9	14,9	14,7	14,4
TES 5 - 5	3	13,6	16,5	17,8	18,4	18,5	18,3	17,8	17,2
TES 5 - 6.5	4	18,3	22,1	23,9	24,6	24,7	24,3	23,6	22,7
TES 12 - 8	5	20,3	24,3	26,0	26,6	26,5	25,9	25,1	24,0
TES 12 - 9.5	6	25,0	29,8	31,6	32,1	31,7	30,8	29,6	28,1
TES 12 - 10	7	30,2	35,4	37,0	36,9	35,9	34,4	32,6	30,5
TES 20 - 12.5	8	40,1	48,0	51,1	51,9	51,5	50,2	48,3	45,9
TES 20 - 13	9	47,2	55,4	57,7	57,3	55,4	52,7	49,4	45,9
TES 55 - 15	10	57,4	66,5	68,7	67,9	65,5	62,3	58,5	54,5
TES 55 - 17	11	71,0	80,8	82,1	79,9	76,1	71,4	66,4	61,3
TES 55 - 20.5	12	92,0	103,5	104,0	100,1	94,3	87,6	80,6	73,7
TES 55 - 28.5	13	109,9	128,4	133,1	131,8	127,1	120,4	112,7	104,4

Δt_{sub}	1 K	4 K	10 K	15 K	20 K	25 K	30 K	35 K	40 K	45 K	50 K
Correction factor	[illegible]	1.00	1.11	1.20	1.28	1.36	1.44	1.52	1.59	1.67	1.75

Then if you look at what our typical selection table will look like and here are the valve numbers, then we have an orifice number. So, the valves with interchangeable orifice, we can put any one of the orifices and then, for a predefined pressure drop, there is a flow, the refrigerant capacity that is defined here where the compensation for the sub cooling.

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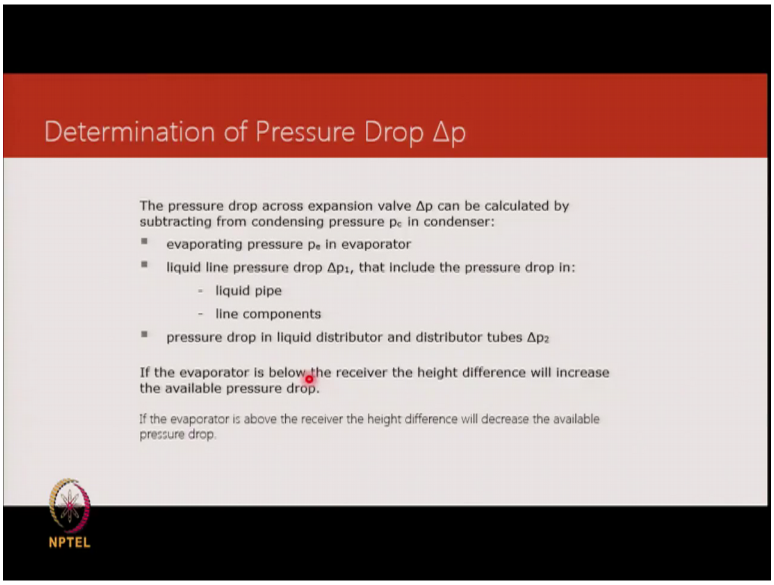

So, if you are looking at the pressure drop across the expansion valve, some of the easy steps would be to look at evaporator pressure condenser pressure and then, what are the pressure drops across line components. So, whatever line component you will choose, there is a filter dryer distributor. You will know what it is. A pressure drop you can calculate, the pressure drop in the pipelines and then, come to a number which represents pressure drop across the expansion valve and then, we also address some of the height differences and if there is any liquid column that is going to need to be adjusted for the calculations, you will do that.

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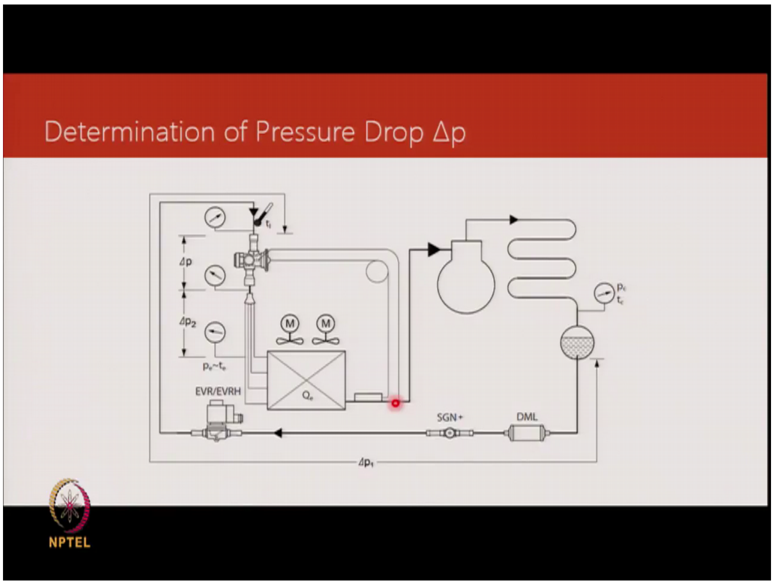

So, this is more like in a schematic how we can look at delta p.

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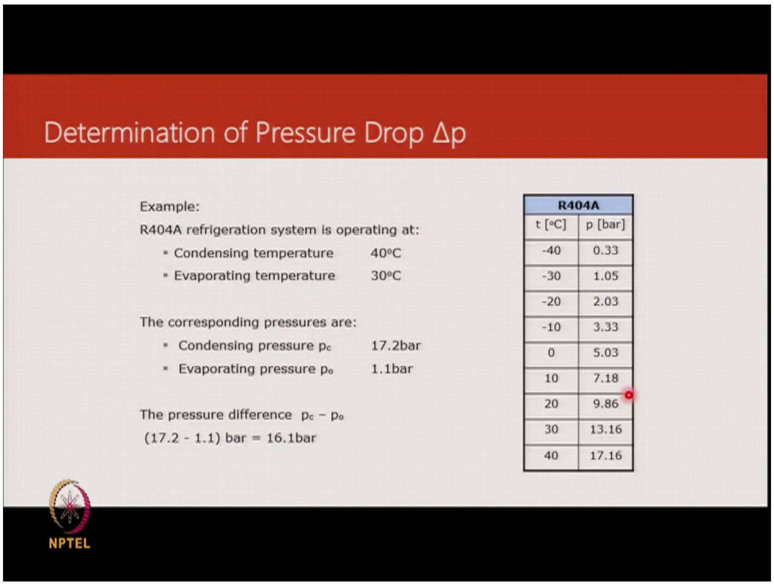

Are you able to follow this? This is just an example of all that I just said that you could pick up a particular refrigerant, you would take the condensing temperature, evaporating temperature subtract get the difference in pressures and then, also take care of whatever is there in the lines. So, with this we are more or less done with the thermostatic expansion valve selection criteria and an overview of how it operates and I would like to conclude our session today over here.

Thank you.