Chemical Process Utilities
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Lecture No # 11
Lecture No # 52
Introduction to Refrigeration

Welcome to the next lecture of introduction to refrigeration under the ages of chemical process utilities. Now in the previous lecture we have learned about the various concepts of refrigeration including the introduction to refrigerant. In this particular lecture we classified about the different kind of refrigerants like hallow carbons, hydrocarbons, inorganic compounds, azeotropic mixtures, non-azeotropic mixtures. We discussed about the various kind of coding system, in the refrigerants under the edges of prefix and coding for refrigerant.

We discussed about the concept of isomers in the refrigerant system and we discussed about the introduction to the refrigeration and its history because this refrigeration is having rich legacy. Now in this particular lecture we are going to discuss about the different type of refrigeration system and cycles.

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We will discuss about the refrigeration system components different type of components involved in the refrigeration system. Like compressor this we will discuss about the compression ratio then the compression efficiency and we will discuss about the various factors those who are affecting the compression efficiency. Then we will discuss about the measures through which we can control the compressor capacity. Then we will discuss about the condenser air cooled condenser, water cooled condenser and evaporative systems.

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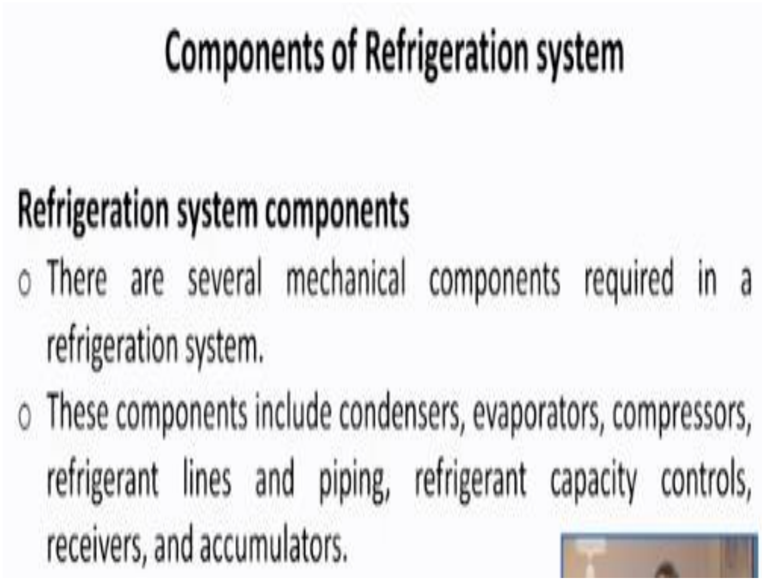

Now let us talk about the different components of refrigeration system now refrigeration system there are various mechanical components associated in the refrigeration system. Now these components are having the condensers different type of evaporators, compressors, refrigerant lines, piping network there are various components attached to the refrigeration system. Those who are dedicated to the refrigerant capacity control there are various receivers accumulators etcetera so, it is a complete system.

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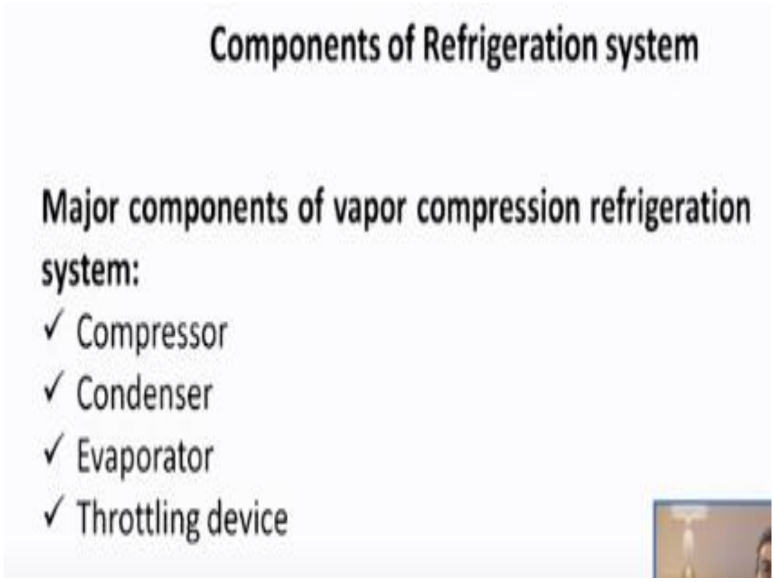

Now when we talk about the major components and especially because the, refrigeration is governed by the different type of a cycles. And vapor compression refrigeration cycle is one of the foremost; cycle being used in the refrigeration system. So, the major component used in, the compressor refrigeration systems are compressor, condenser, evaporator, throttling devices.

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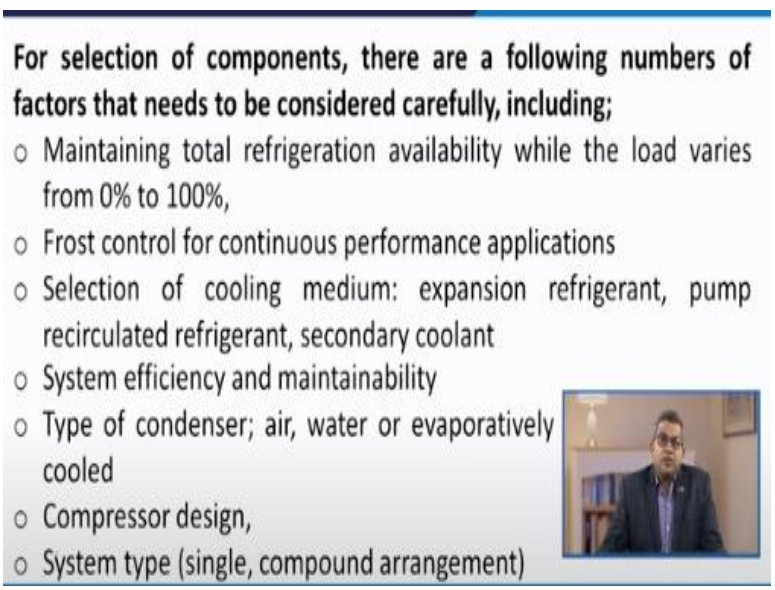

Now question may arise that for what kind of a different selection criteria to be adopted for components. So, there are various factors, need to be considered while we select various components for refrigeration system. One is that maintenance aspect that is the maintaining total refrigeration availability while the load varies from 0 to 100% so it should sustain for the varying load capacity.

Then there must be certain factors involved in the frost control because the frost control is again a very crucial aspect in the refrigeration system and this is again very important for the performance application. Then another factor which is very important for the refrigeration system is the selection of cooling media expansion refrigerant, pump, recirculation aspect then secondary coolant etcetera.

Then what should be the system efficiency and how we can maintain it under the edge of maintainability. Then which kind of the condenser we need to use whether air condenser, water condenser or evaporative cooled condenser? Then what should be the compressor design and what kind of the system we are using single or compound type of arrangement.

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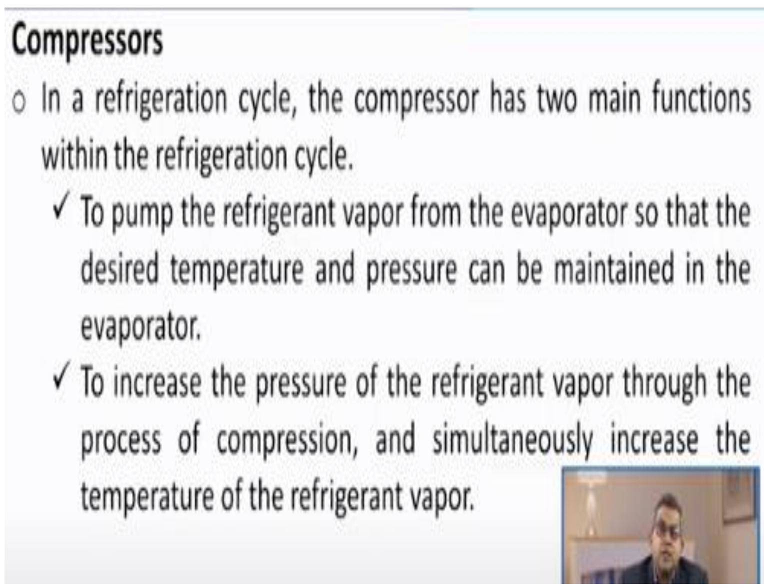

So let us talk about the compressor because the compressor the compressor is the heart of any kind of refrigeration system. So, in a refrigeration cycle the compressor has 2 main functions within the refrigeration system. One is to pump the refrigerant vapour from evaporator so that the desired temperature and pressure can be maintained in the evaporator. Second is to increase the pressure of the refrigerant vapor through the process of compression and simultaneously increase the temperature of the refrigerant vapor. Now as I told you that it is the heart of vapor compression refrigeration system it can be divided into 2 main categories.

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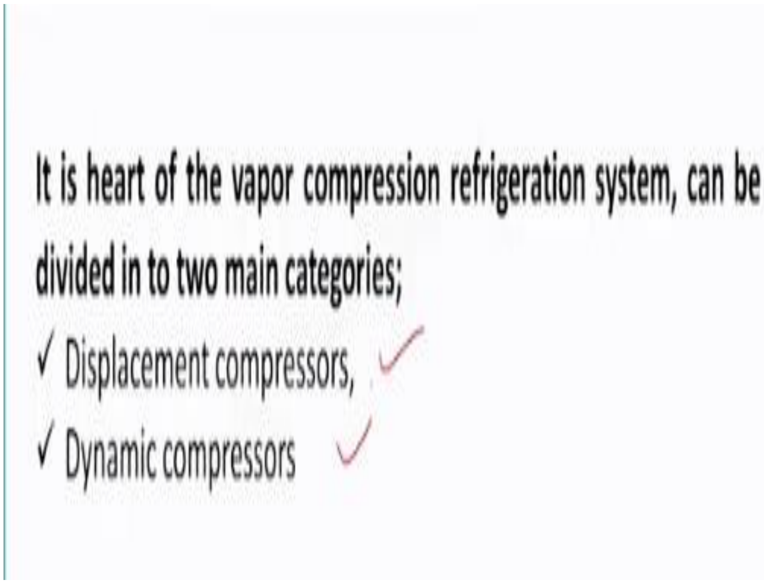

One is the displacement compressor and another one is the dynamic compressors.

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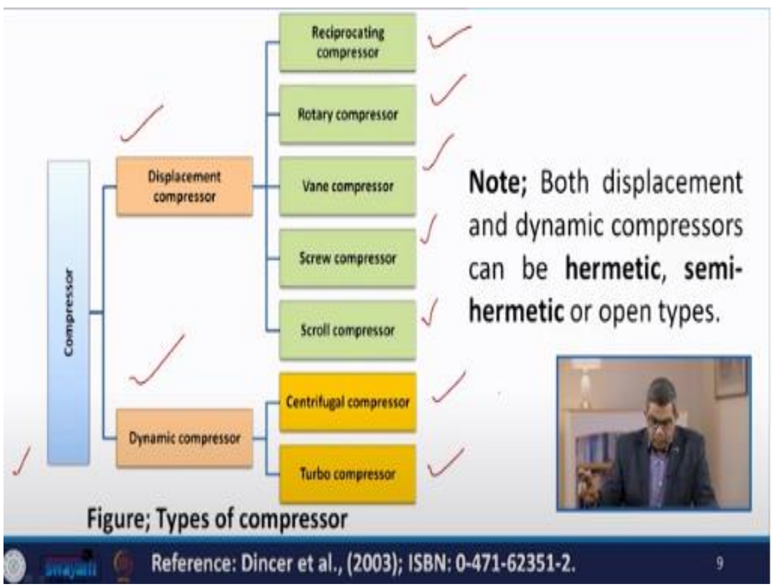

Now again if we take the classification of compressor then the broad type of classification can be given in this particular figure. That deals with displacement as well as dynamic compression system it may be hermetic, semi hermetic type or open type. So, compressors basically they are divided in 2 different categories one is the displacement compressor and second one is the dynamic compressor.

Now when we talk about, the displacement compressors so again they are divided in 5 different categories reciprocating compressor, rotary compressor, vein compressor, screw compressor, scroll compressor. And dynamic type of compressor again they are sub divided into 2 different categories one is the centrifugal compressor and second one is the turbo compressor.

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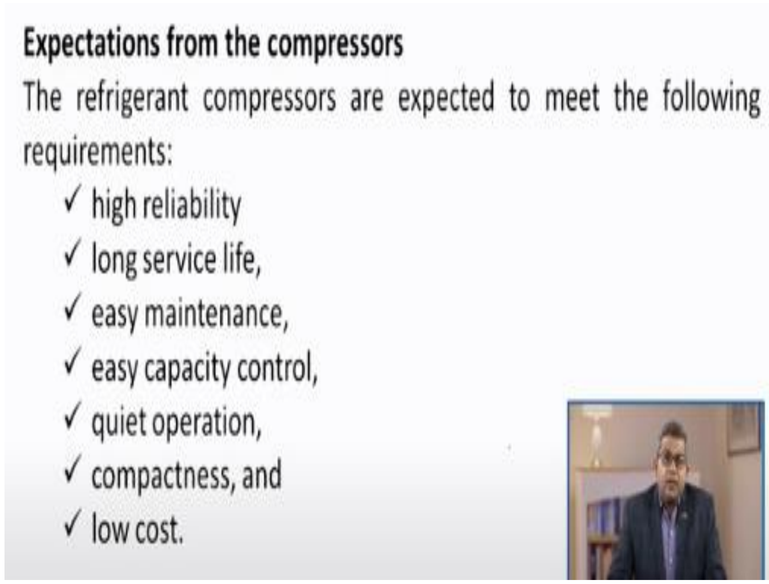

Now usually when we talk about the compression units especially in terms of refrigeration cycle there are various expectations one can have from the compression unit. And when in a scientific way we need to chalk down or all these expectations then they must meet the different requirement. Like they should be highly reliable in nature, they must possess the long service life because every time if we are changing the system or we are facing the difficulty in the maintenance then the cost factor will be on the higher side.

Therefore, it should be easy maintainability concept, there they should have an easy capacity control, and they must have a silent operation that is called the quiet operation. Because in case of if they have a high noise then definitely it may create a noise pollution. They must have the compactness and above all they must possess the low-cost aspect.

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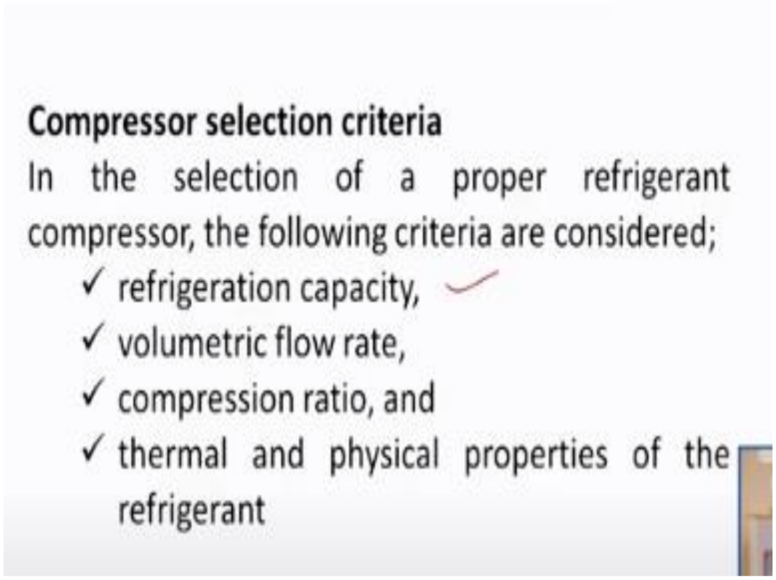

So; all these expectations are desirable for smooth functioning of any kind of a compression especially applicable for the vapour compression depreciation system. So, since we have discussed there are variety of compressors available as on date based on the classification scheme then there must be certain criteria for the compressor selection. Now in the selection of different type of refrigerant there must be following criteria.

Now first is that what should be the refrigeration capacity then what different kind of volumetric flow rate we need to have? And that purely depend on the design criteria of the refrigeration cycle as well as the refrigerant what we are using in question. Then what compression rates show we are looking for that is again the major selection criteria. And then the thermal and physical properties of the refrigerant are again very important because this particular information or this, particular properties are essential to look the compatibility issue with respect to the compressor.

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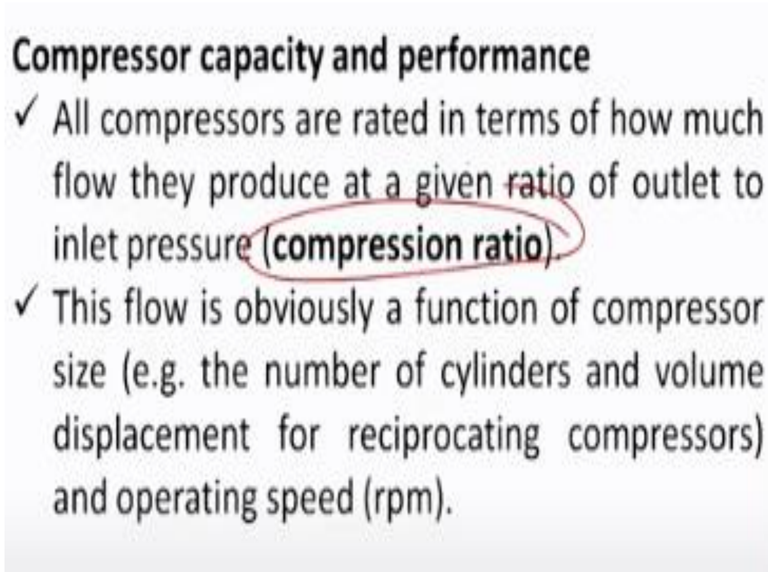

Then another concept is very prominent that is the compressor capacity and the performance. So, all compressors are rated in terms of how much flow they produce at a given ratio to outlet or to the inlet pressure and that is called the compression ratio. Now this flow is obviously a function of compressor size that is the number of cylinders and volume displacement for reciprocating compressor and operating speed usually represented in rpm.

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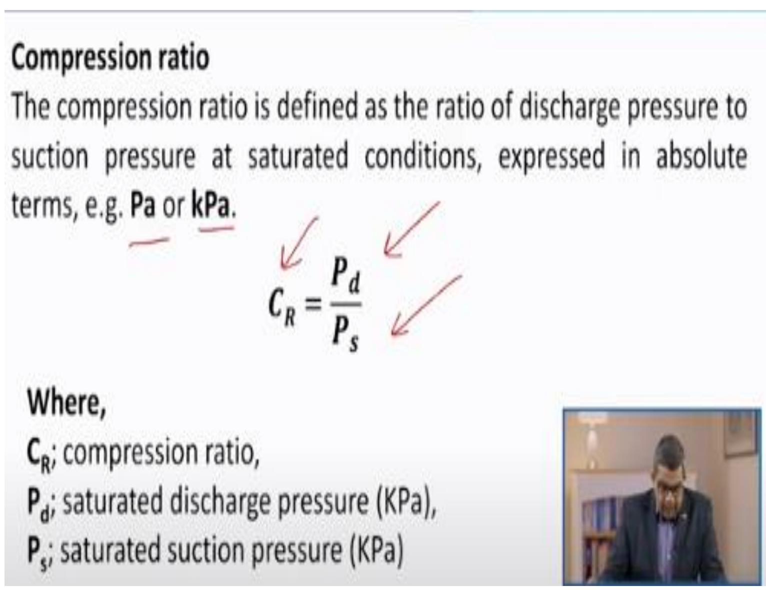

Now let us talk about the compression ratio the compression ratio is defined as the ratio of discharge pressure to the suction pressure at saturated condition and usually expressed in terms of absolute terms like Pascal or kilo Pascal. Now here C_R is the compression ratio this is equal to the saturated discharge pressure represented as, KPa and the unit is the kilo Pascal over saturated suction pressure represented as the Ps and having the unit of kilo Pascal.

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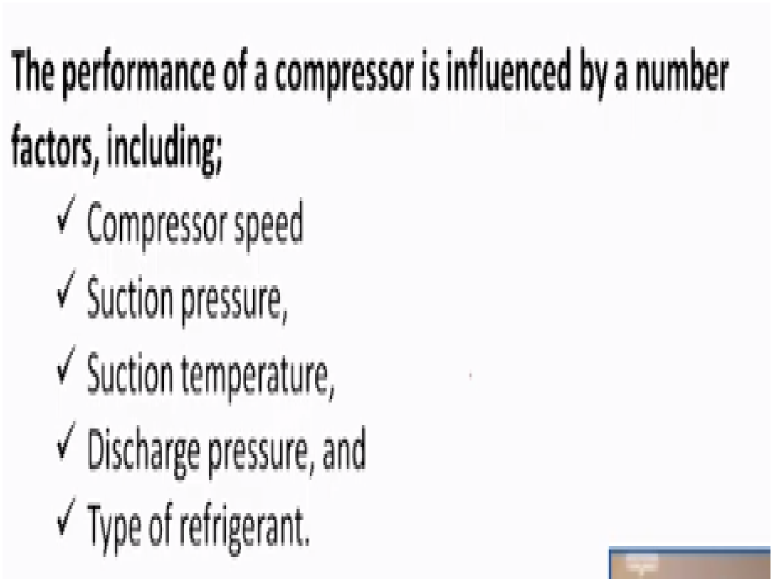
The compression ratio is;

$$C_R = \frac{P_d}{P_s}$$



Now usually when we talk about the compression in the refrigeration cycle so the performance is always, be a very big challenge. So, the performance of compressor is usually influenced by a number of factors this includes the compressor speed, this includes the suction pressure, suction temperature, discharge pressure and what kind of refrigerant we are using in that particular refrigeration cycle. So, all these are the contributory factor towards the performance of the compressor.

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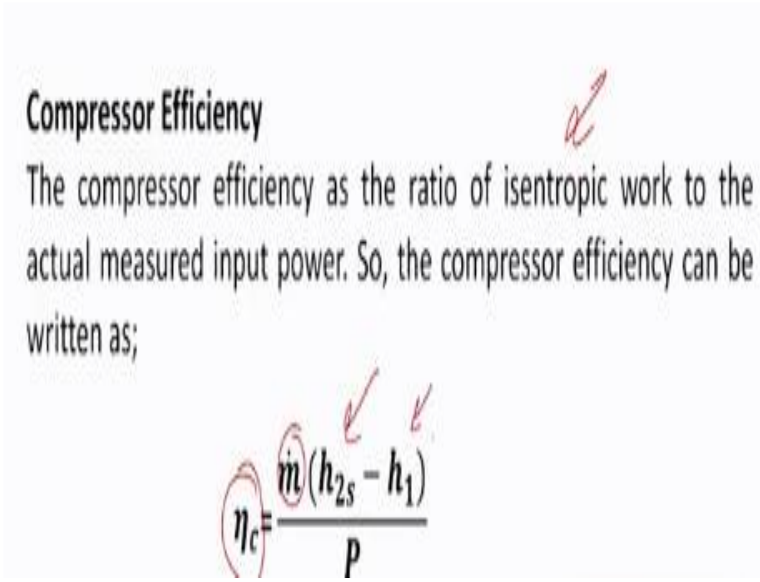

So, when we talk about the performance of compression then we cannot overlook the importance of the compressor efficiency. Now the compressor efficiency is as the ratio of isentropic work to the actual measured input power. So, the compressor efficiency can be written as compression efficiency is equal to m into h2s – h1 upon P.

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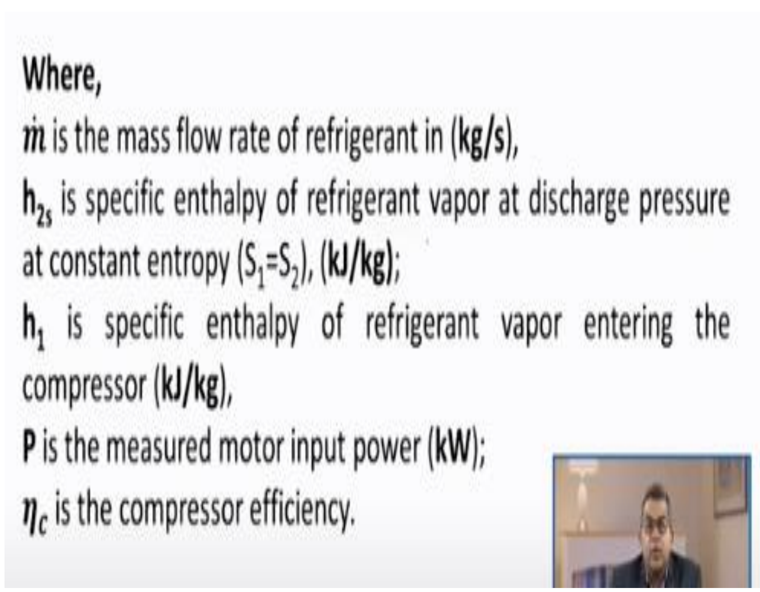
The compression efficiency will be;

$$\eta_c = \frac{\dot{m}(h_{2s} - h_1)}{P}$$



Now where; the m is the mass flow rate of refrigerator that is represented in kilogram per second. h2s is the specific enthalpy of refrigerant vapor at discharge pressure at constant entropy. And when $S_1 = S_2$ and the unit of this h2s is kilo joule per kilogram similarly this h1 is the specific enthalpy of a refrigerant vapor entering the compressor and that is again having the unit of kilo joule per kilogram. And p is the measured motor input power and it is having the unit of kilowatt and eta c compressor efficiency.

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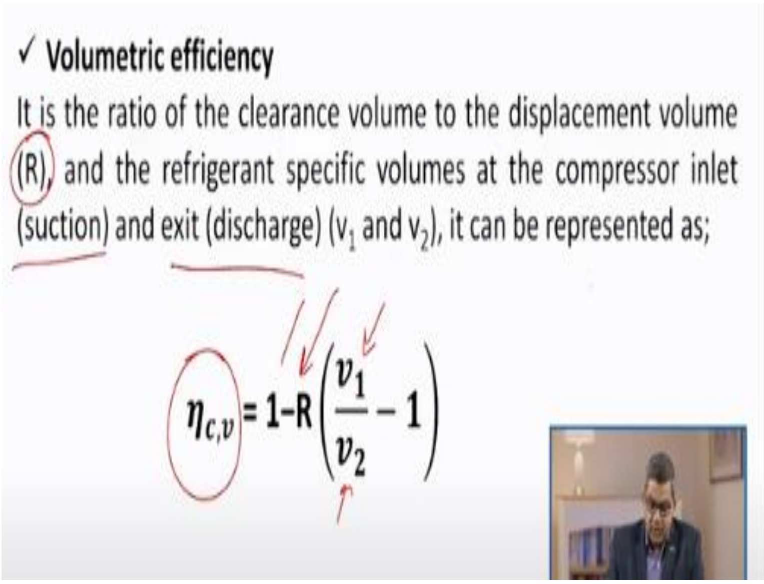

Now let us talk about the volumetric efficiency now it is the ratio of clearance volume to the displacement volume R. And the refrigerant specific volumes at the compressor inlet suction that is referred as suction and exit that is discharge v1 and v2. So, in mathematically if we need to represent this volumetric efficiency so this is a volumetric efficiency and 1 - R that is the displacement volume into v1 upon v2 – 1. So that is the volumetric efficiency.

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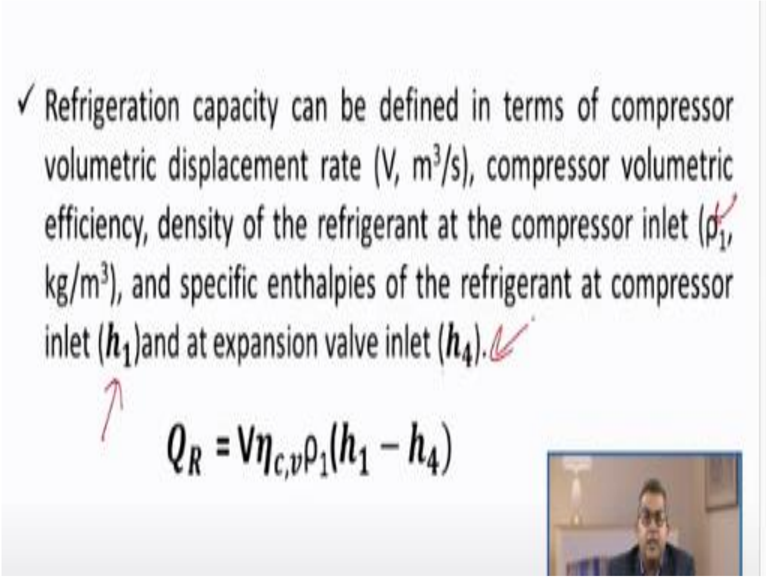
The volumetric efficiency is;

$$\boldsymbol{\eta_c = 1 - R(\frac{v_1}{v_2} - 1)}$$



Now sometimes people talk about the refrigeration capacity now the refrigeration capacity can be defined in terms of compressor volume displacement rate. And that is V and unit is meter cube per second and the compressor volumetric efficiency density of the refrigerant at the compressor inlet that is rho 1 and having the unit of kilogram per meter cube. And specific enthalpies of the refrigerant at compressor inlet that is h 1 and at expansion valve inlet h 4. So, this Q_R = V eta c,v rho1 into h1 - h4.

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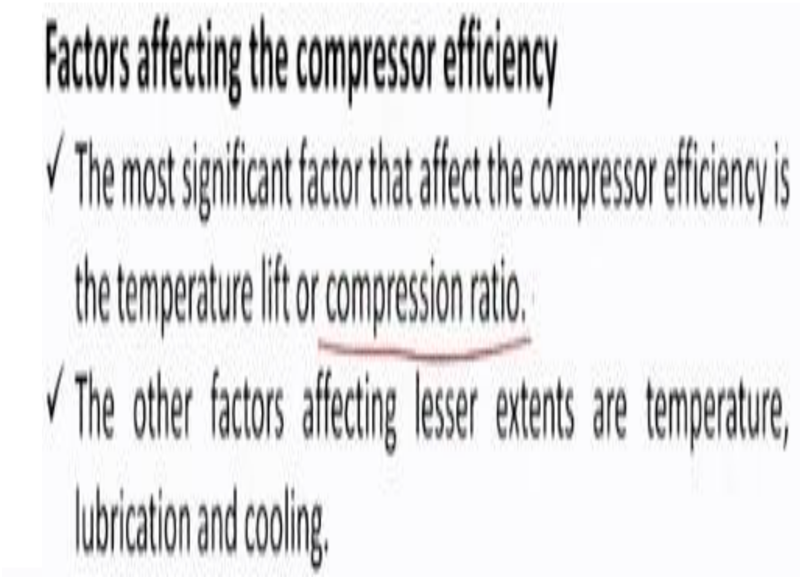
Refrigeration capacity can be defined as;

$$Q_R = V\eta_{c,v}\rho_1(h_1 - h_4)$$



Now there are various factors those who are affecting the compressor efficiency the most significant factor that affect the compressor efficiency is the temperature lift or the compression ratio. The other factor those who are affecting um they are less extent they are the temperature sometimes lubrication and cooling but they do have some sort of effect over the compression efficiency.

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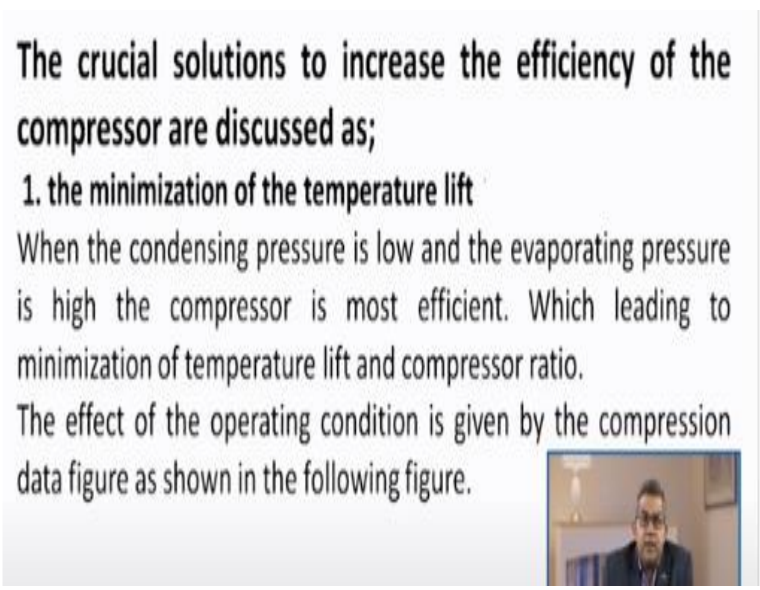

Now the crucial solution to increase the efficiency of the compressor there are certain factors involved like one is the minimization of temperature lift. Now when the condensing pressure is low and the evaporating pressure is high the compressor is most efficient which lead to minimization of temperature lift and compressor ratio. The effect of operating condition is usually given by the compression data.

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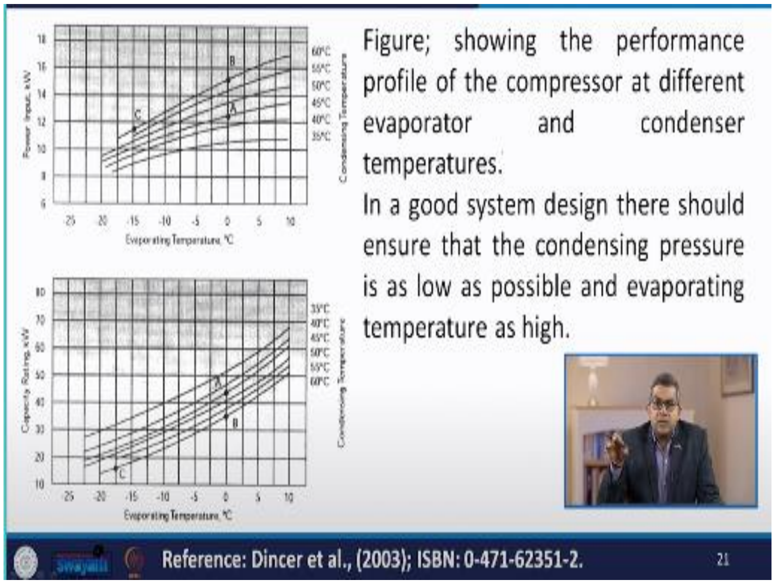

Which we have represented in this particular figure, now this figure shows the performance profile of the compressor at a different evaporator and condenser temperature. Now in a good system design there should ensure that the condensing pressure is as low as possible and evaporating temperature as high.

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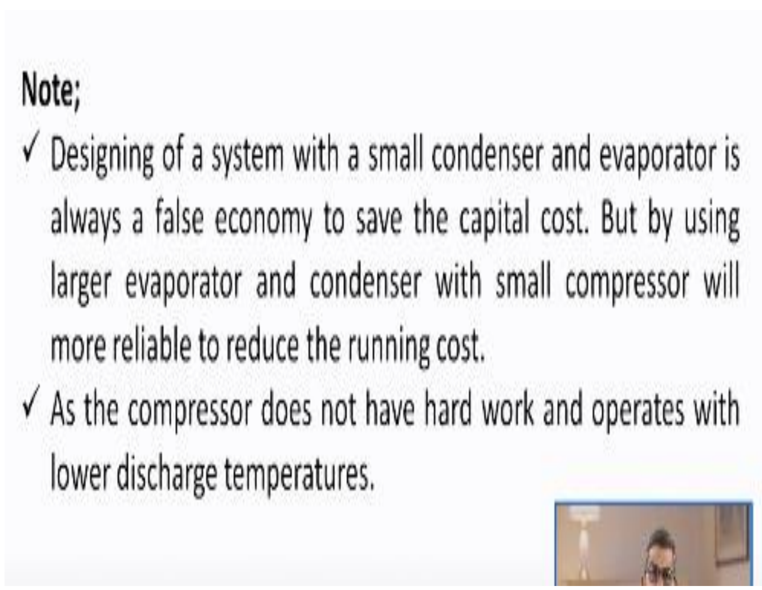

Now designing of a system with a small condenser and evaporator is always a false economy to save the capital cost. But by using larger evaporator and condenser with small compressor will more reliable to reduce the running cost and that is the rule of thumb. Now as the compressor does not have hard work and operates with a lower discharge temperature. Now another aspect is that is the, to alter the compression efficiency is the lowering the suction temperature.

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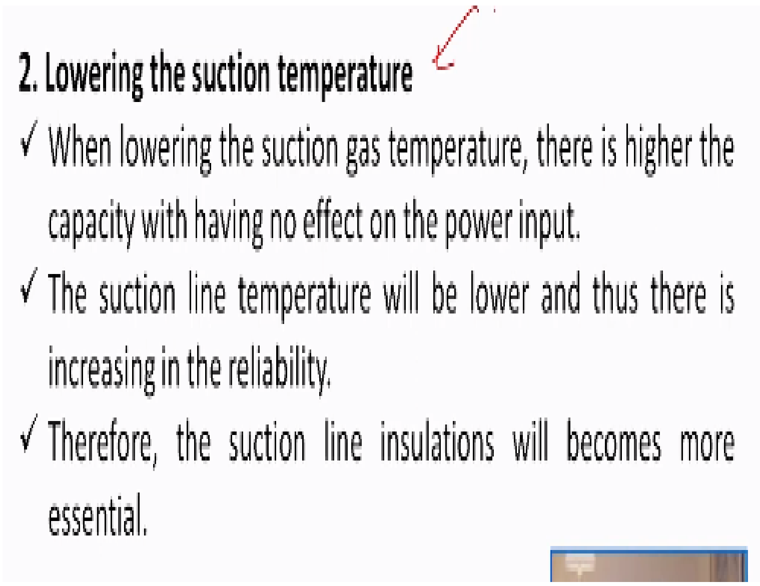

Now when lowering the suction gas temperature there is a higher capacity with having no effect on the power input. The suction line temperature will be lower and there is an increase in the reliability therefore the suction line insulation will become more essential in that particular case. Now another aspect is that the use of effective lubrication and cooling the compressor at every time should be lubricated and efficiently cooled with the help of some kind of a chiller or cooling tower in case of larger equipment used in the industry.

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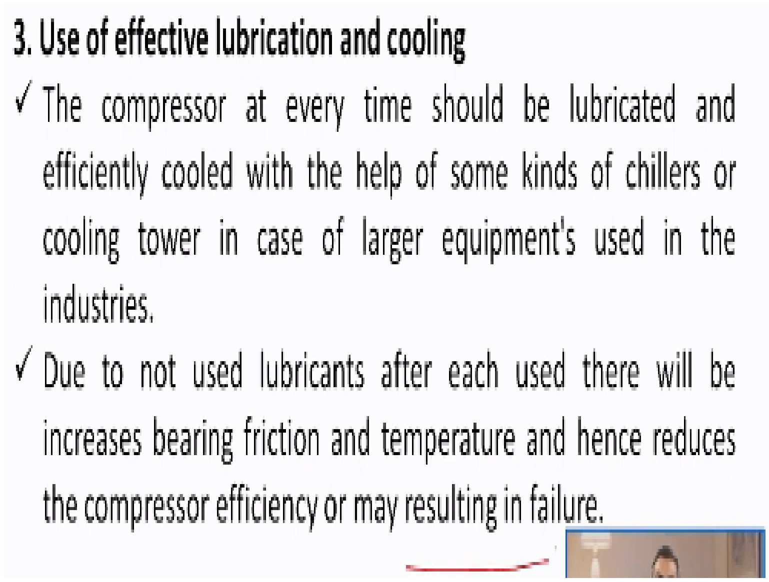

Now due to not used lubrication or lubricant after each use there will be an increase bearing friction and temperature. Therefore, it reduces the compression efficiency or sometimes may result in failure because of the repeated use. And sometimes because of the friction the temperature may go on at the higher level and this may dissociate the various kinds of a chemical component in the lubricant and that may create a problem for the smooth operation of compressor.

Now let us talk about the capacity control aspects of compressor now it is a unit which the compressor ability can be controlled by reduce or increase the refrigerant mass flow rate. Now the compressor flow can, improved or improvised with respect to the performance in 2 ways. one is by using the efficient compressor capacity reduction to prevent the increase in the flow rate of refrigerant at high temperature therefore the coefficient of performance of the compressor at higher temperature higher ambient can be increased.

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The second is by change in the system sizing strategy now conventional heat pumps they are sized for the cooling load so that the comfortable air conditioning can be achieved or can be obtained.

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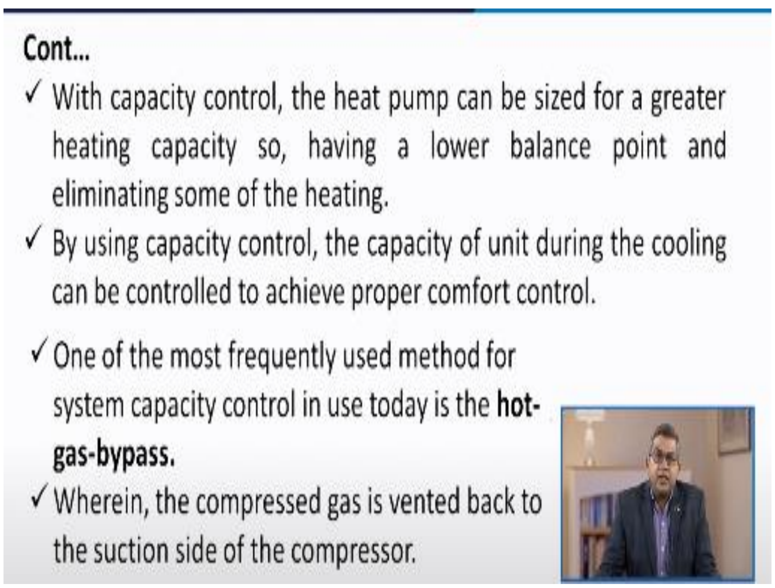

Now with the capacity control the heat pump can be sized for a greater heating capacity therefore having a lower balance point and eliminating some of the heating. Now by using capacity control the capacity of a unit during the cooling can be controlled to achieve the proper comfort control. Now one of the most frequent used methods for system capacity control in today is the hot gas bypass. The compressed gas in this particular approach is vented back to the suction side of the compressor.

The other possible capacity control methods they fall into the different categories and especially there are 3 different categories such as speed control, clearance volume control and the valve control.

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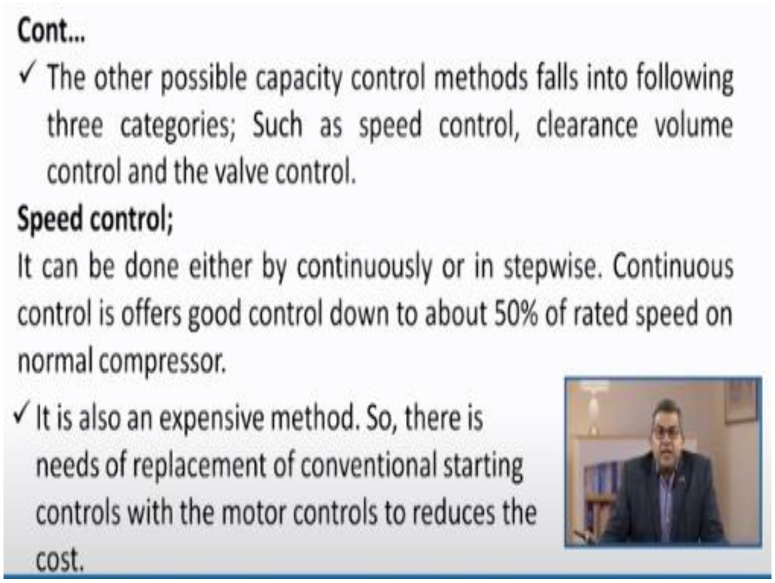

So let us talk about these things in brief so first the speed control now it can be done either by continuously or in step wise. The continuous control is usually this continuous control offers good control down to about 50% of rated speed on normal compressor. Now it is also an expensive method so there is a need of replacement of conventional starting control with the motor control to reduce the cost.

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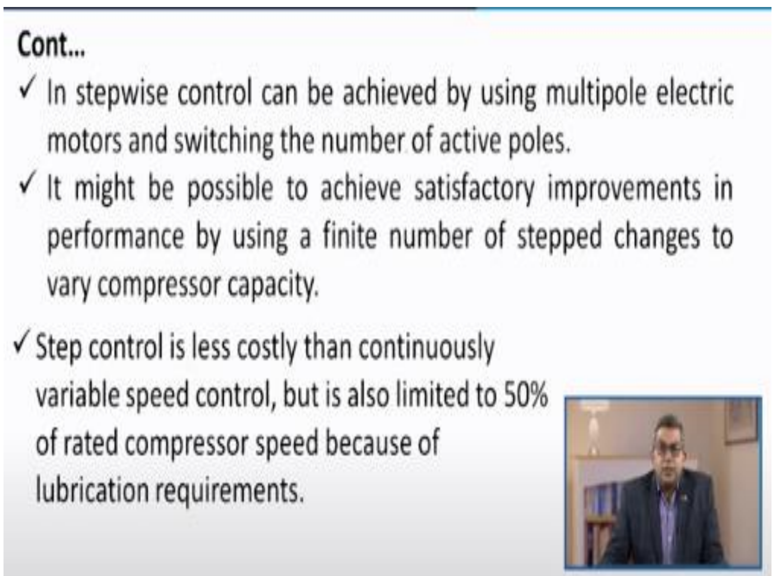

Now if we talk, about the step control, in step control this can be achieved by using multipole electric motor and switching the number of active poles. Now it might be possible to achieve satisfactory improvisation in performance by using a finite number of stepped changes to vary compressor capacity. Now step control is less costly than the continuous variable speed control but it is also limited to 50% of the rated compressor speed because of the lubrication requirement.

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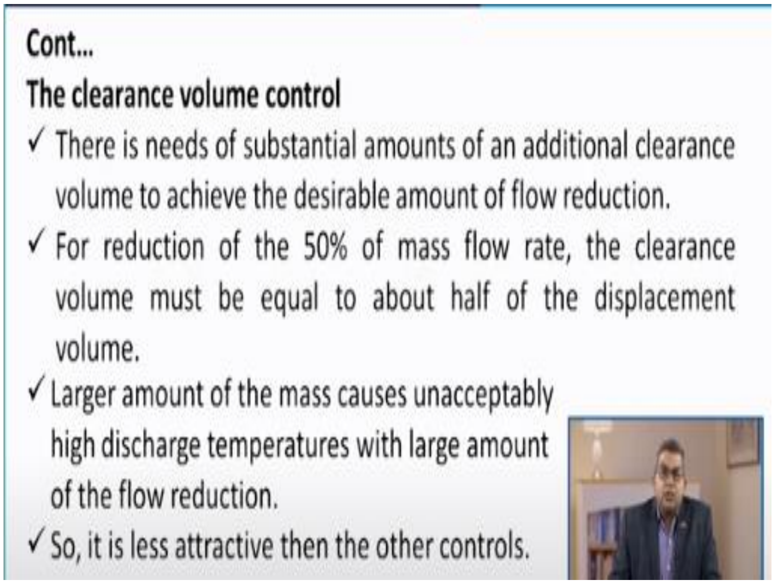

Another is the clearance volume control now there is a need of substantial amount of an additional clearance volume to achieve the desirable amount of flow reduction. For reduction of say 50% of mass flow rate the clearance volume must be equal to about half of the displacement volume. Larger amount of the mass this may cause unacceptability with high discharge temperatures with a large amount of flow reduction. So, it is less attractive than other controls.

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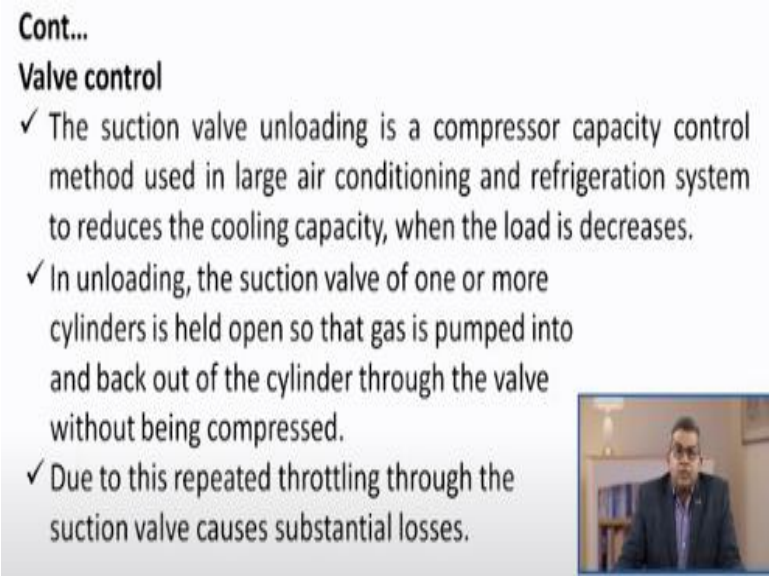

Now let us talk about the valve control the suction valve unloading is a compressor capacity control method used in large air conditioning and refrigeration system to reduce the cooling capacity when the load is decreased. Now in unloading the suction valve of one or more cylinders usually they are held open so that the gas is pumped into and back out of the cylinder through the valve without being compressed. Now due to this repeated throttling through the suction valve this can cause a substantial loss.

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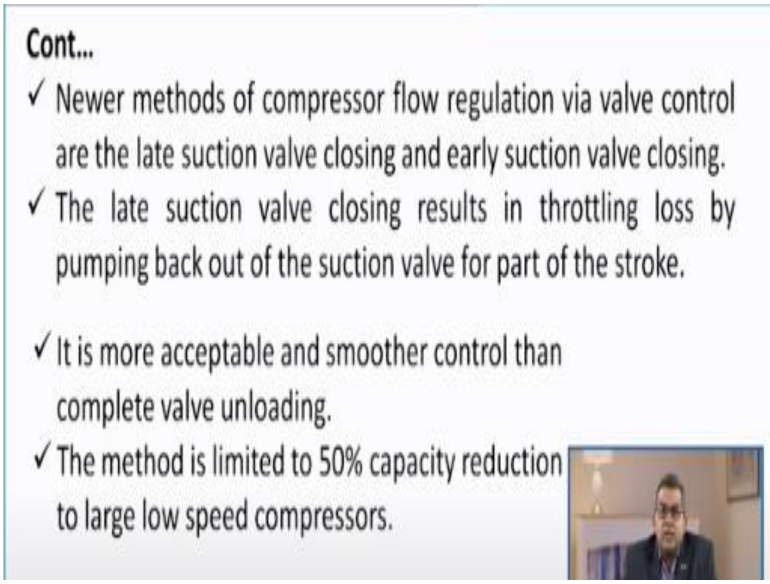

Now newer method of, compressor flow regulation via valve control are the late suction wall closing and early suction valve closing. The, late section valve closing result in throttling loss by pumping back out of the suction wall for part of the stroke. Now it is more acceptable and smoother control than complete valve unloading this particular method is limited to 50% capacity reduction to large low speed compressor.

The early section valve closing eliminates the losses due to the throttling gas back out of the suction valve. The suction valve just upstream of the suction valve is closed on the intake stroke which limiting the amount of gas taken in.

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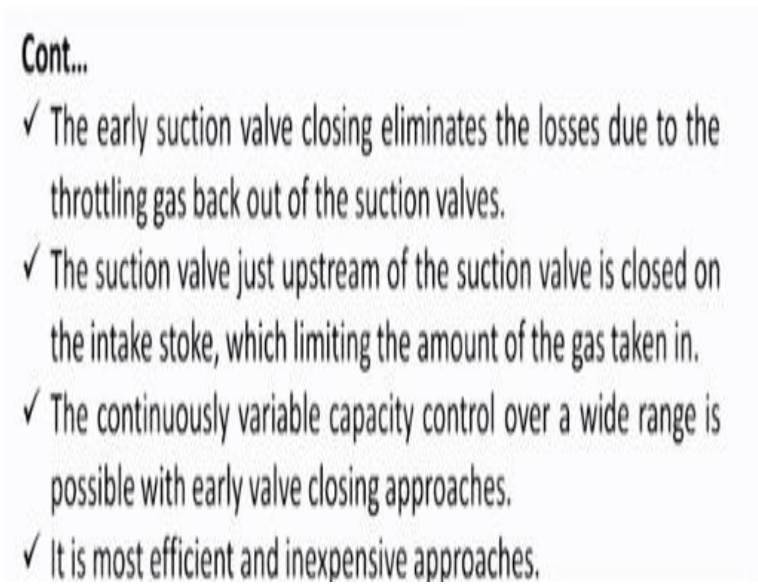

Now the continuously variable capacity control over a wide range is possible with early wall closing approaches now this is most efficient and inexpensive approach.

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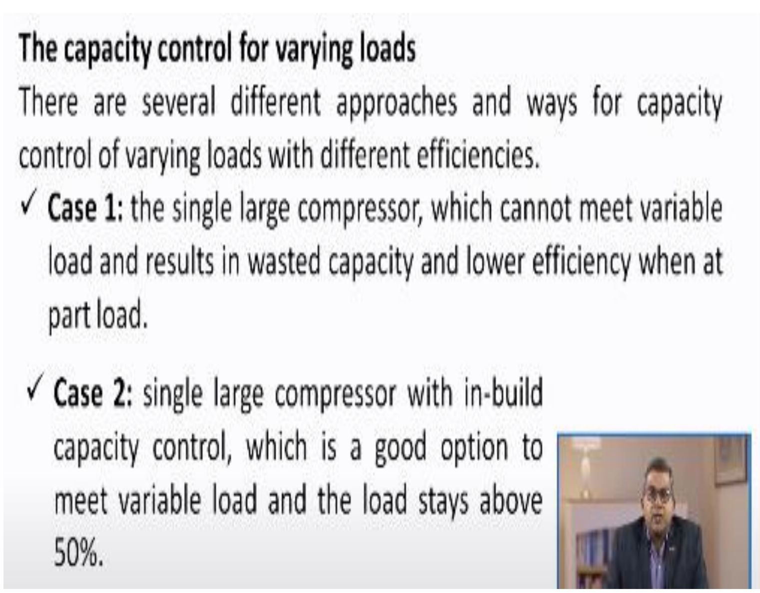

Now let us talk about the capacity control measures through varying load. Now there are several different approaches and ways through which we can control the capacity and one of this is the varying load with the different efficiencies. Now let us talk about different cases now case one the single large compressor which cannot meet variable load and result in wasted capacity the lower efficiency when at part load.

Now case 2 the single large compressor with inbuilt capacity control which is a good option to meet the variable load and the load stays above 50%.

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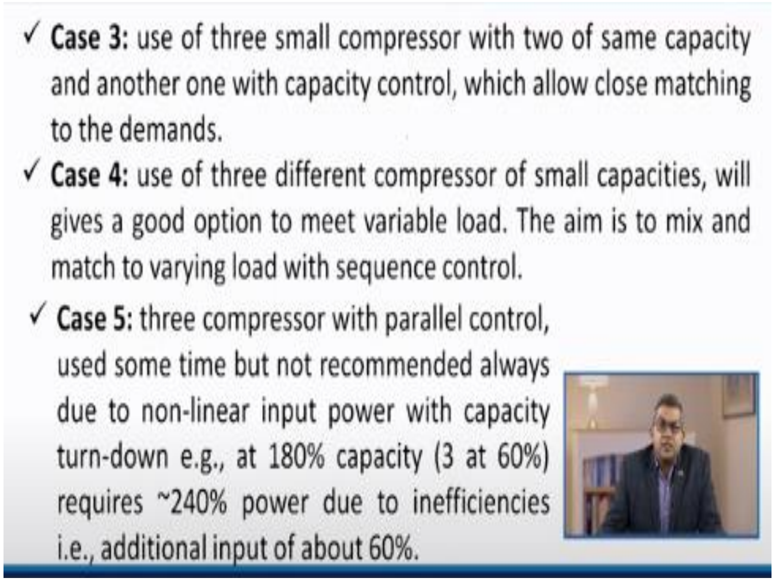

Another case that is case number 3 this use the 3 small compressors where the 2 of the same capacity and another one with the capacity control which allow us to close the matching to the demand. Now case 4 this uses the 3 different compressor of small capacities this gives a good option to meet variable load. The aim is to mix and match to varying load with the sequence control. Case, number 5 now 3 compressors with the parallel control use some time but not recommended always due to nonlinear input power with capacity turned down.

For example, at 180% capacity 3 at 60% requires 240% of power due to the inefficiencies an additional input of about say 60%.

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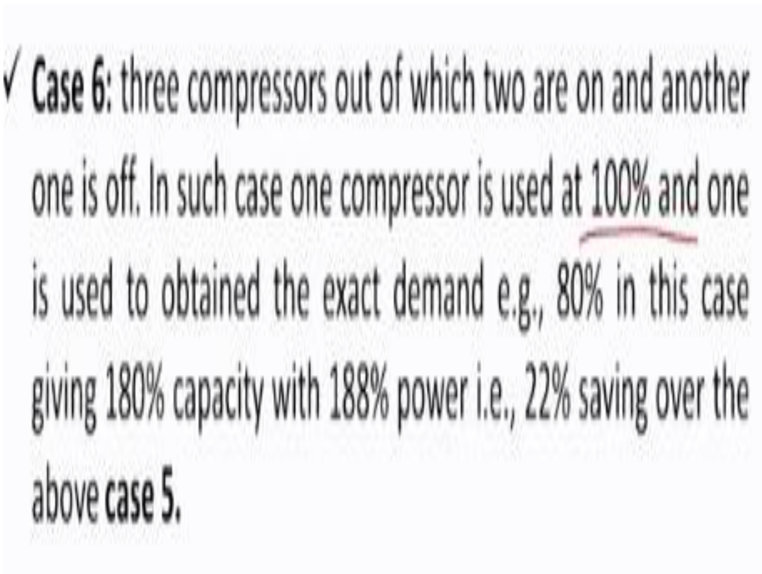

The 3 compressors out of which two are on and another one is off. In such case one compressor is used at 100% and one is used to obtain the exact demand that is 80% in this case giving 180% capacity with 188% power that is 22% saving over if you refer to the case number 5 as a reference media.

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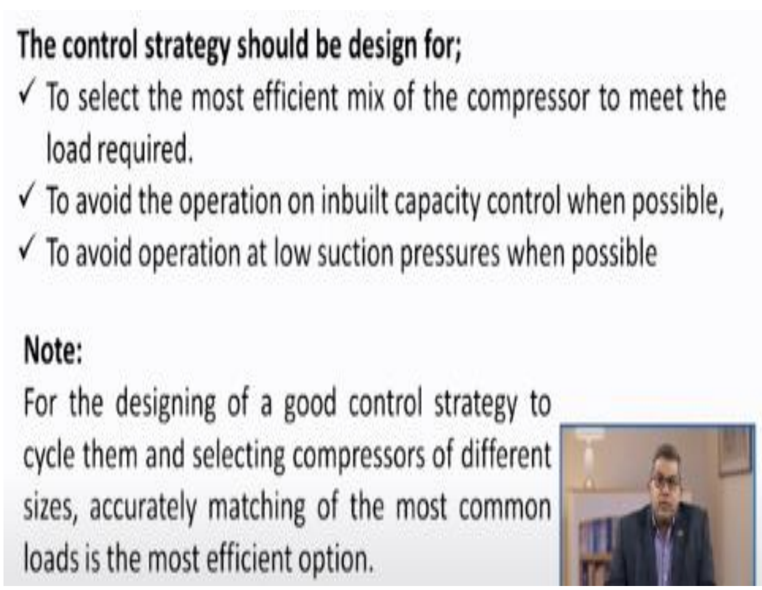

Now the controlled strategy this should be designed for to select the most efficient mix of compressor to meet the load required. Another is to avoid the operation on inbuilt capacity control when possible. And third one is to avoid the operation at low suction pressure when possible. Now for designing of a good control strategy to cycle them and selecting compressor of different sizes accurately matching of most common loads is the most efficient option.

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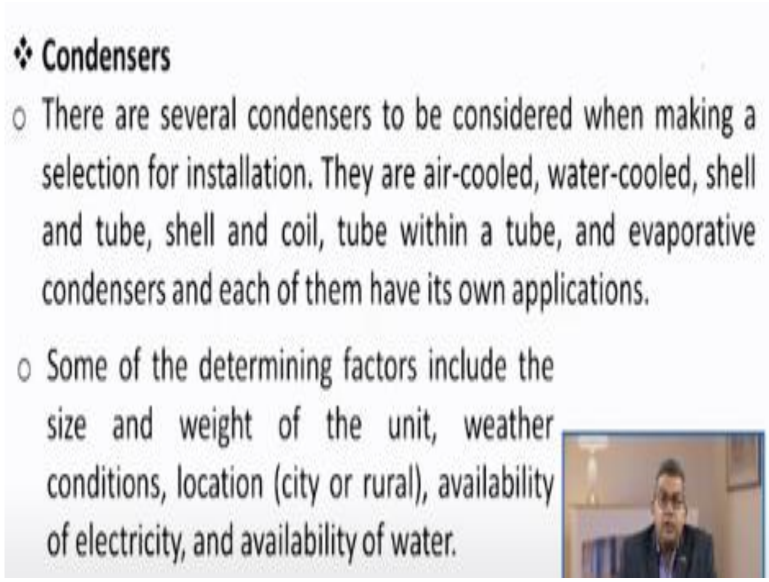

Now let us talk about the condensers there are several condenses to be considered when making a selection for installation. They are air cooled, water cooled, shell and tube type of condenser shell and coil type of condenser tube within tube and evaporative condensers and each of them have its own applications and capabilities. Some of the determining factors include the size and the weight of the unit, weather conditions, locations may be city or rural availability of electricity and availability of water. These are the other determining factor while selecting the appropriate condenser.

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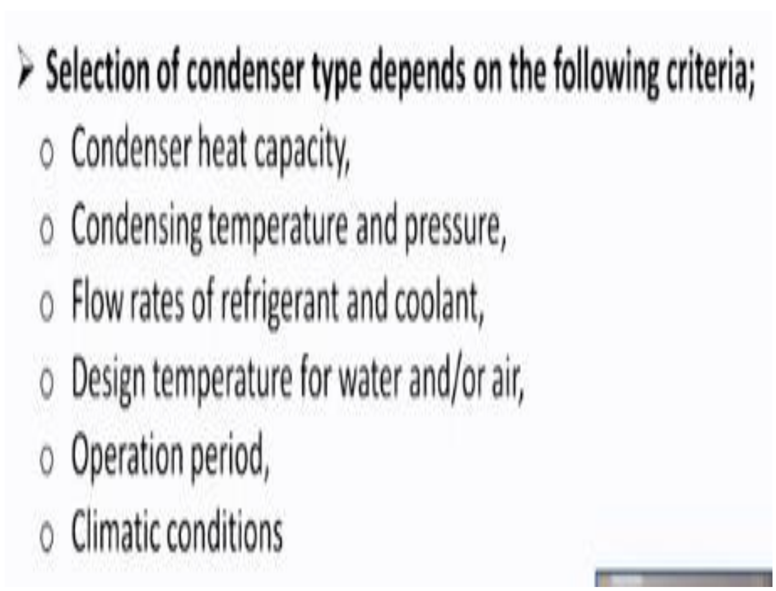

So usually when we talk about the selection criteria for condenser this depends on the condenser heat capacity. What is the heat capacity of the condenser that is one of the designs deciding factor then, condensing temperature and pressure requirement? Apart from this the flow rates of refrigerant and coolant they are also the deciding factor for the proper selection criteria of condenser.

Then design temperature and for water and air and what should be the operating period and the climatic conditions. So, all these, are the governing factor for the appropriate selection of the condenser.

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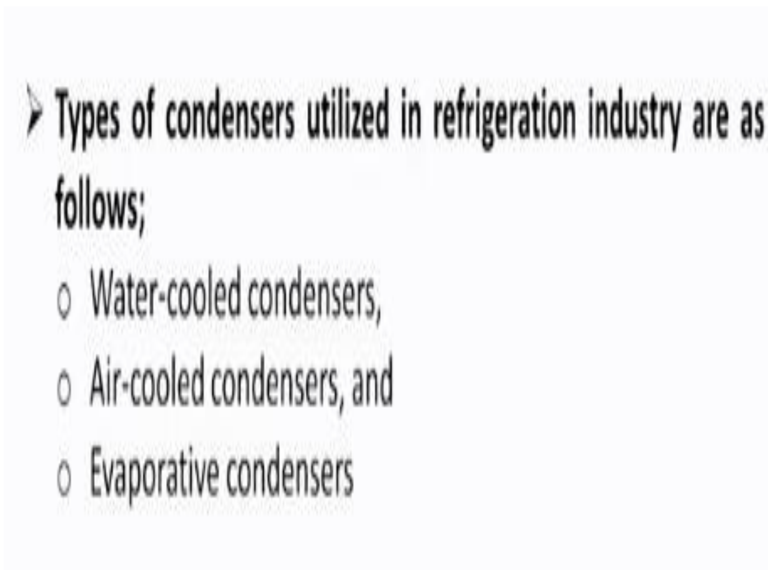

Now let us talk about the different type of condensers those who are being used in the refrigeration industry. One is the water-cooled condenser another one is the air-cooled condenser and third one is the evaporative type of condenser.

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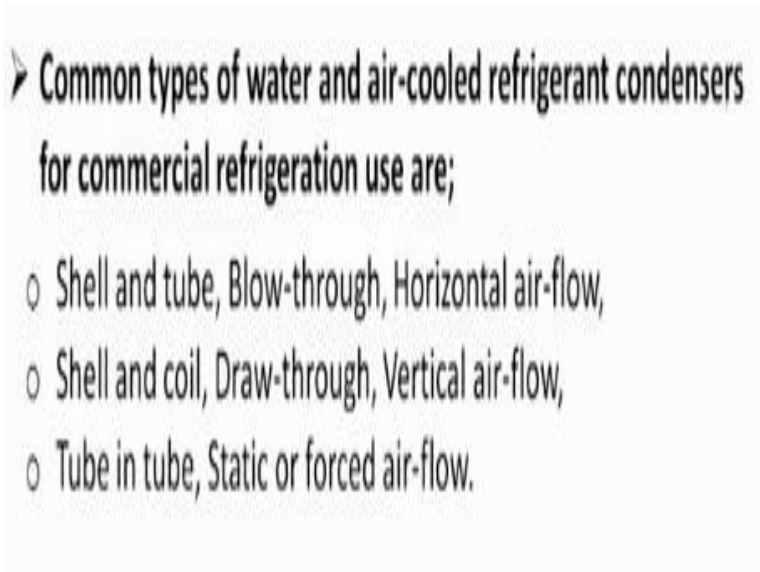

Now there are common type of water in air cooled refrigerant condensers for commercial refrigeration purpose. They are the shelling tube blow through the horizontal air flow, the shell and coil draw through the vertical air flow, tubing tube static or forced airflow.

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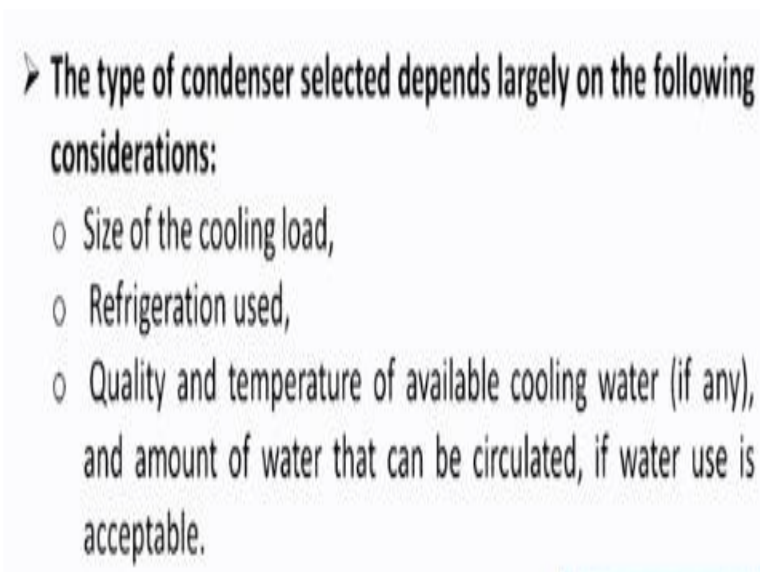

Now the type of condenser selection depends largely upon the different consideration. One is that what is the size of the cooling load second is the different type of refrigeration being used in the refrigeration industry so what kind of the refrigeration used. And then quality and temperature of available cooling water if required and amount of water that can be circulated if water use is acceptable.

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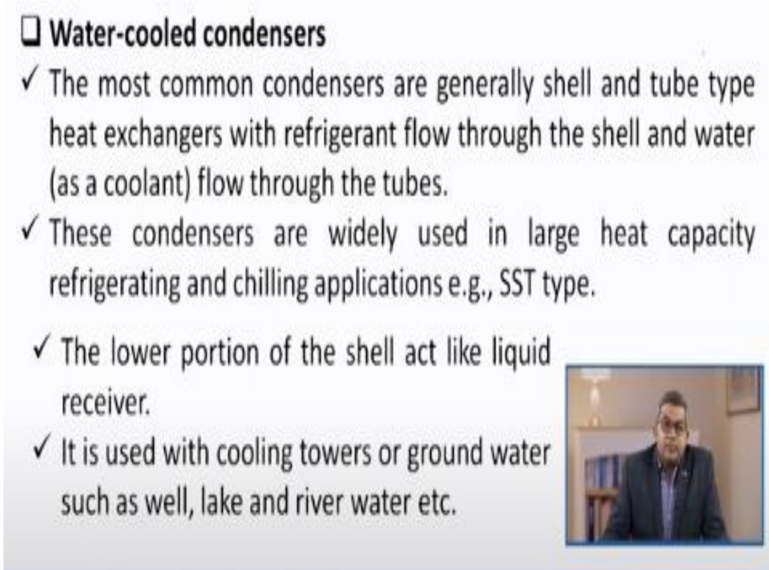

Now water-cooled condenser this is the most common condenser they are generally shell and tube type heat exchanger with the refrigerant flow through the shell and water as a coolant. Now these condensers are widely used in large heat capacities the refrigerating system and chilling operations like SST type. The lower portion of the shell act like liquid receiver, it is used with the cooling tower or ground water such as well lake and river water.

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Now here are some examples of the water cooled condenses like ELT tube and tube type of condenser then shell and tube type of condenser then shell and coil then this is AMC or ammonia type of condenser and this is the coaxial type of condenser.

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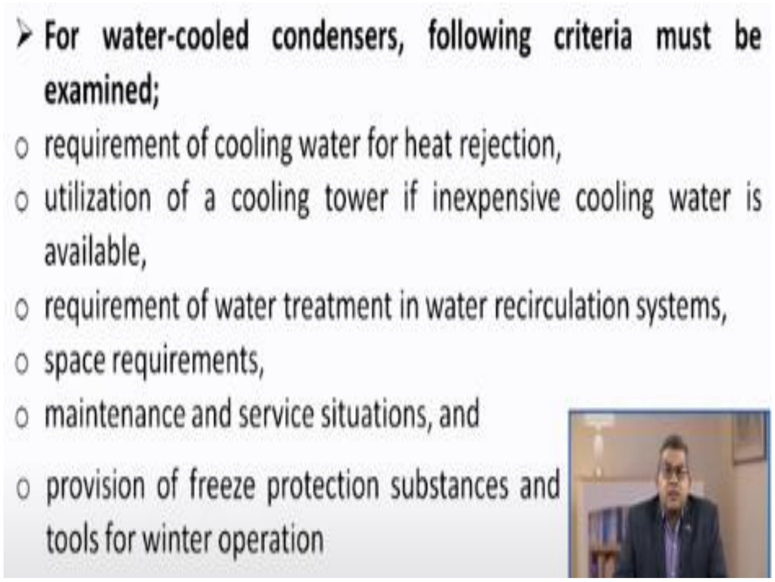

Now for water cooled condenser different criteria must be examined before we go for water cooled condenser. One is that what, is the requirement of cooling water for heat rejection, the utilization of cooling tower if any expensive cooling water is available. Then the requirement of water treatment in water recirculation type of systems, then what is the space requirement. Then maintenance and service situation and the provision of freeze protection substances and tool for winter operation.

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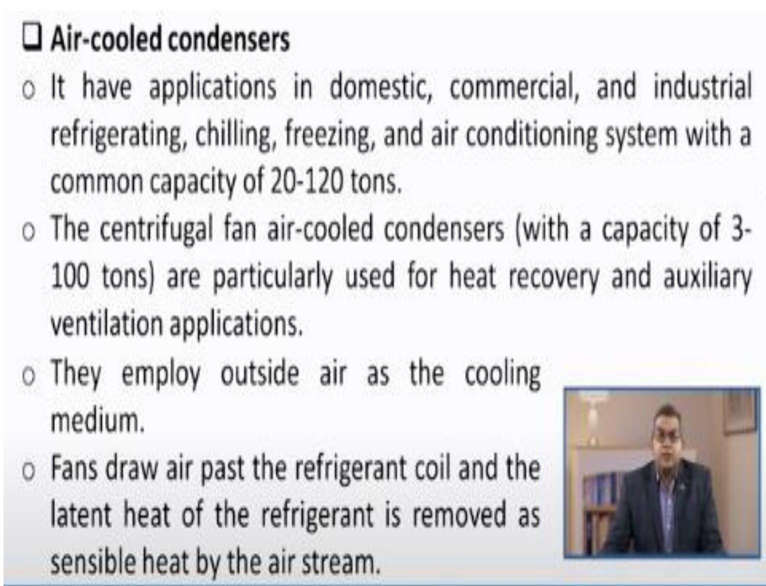

Now let us talk about the air-cooled condenser now it has the application in domestic, commercial and industrial refrigerating chilling, freezing and air conditioning system with a common capacity of 20 to 120 tons. The centrifugal fan air cooled condenser with the capacity of 3 to 100 tons they are particularly used for the heat recovery and auxiliary ventilation application.

Now they employ outside air as a cooling media because air is having thermal properties. Now the fan draws air past the refrigeration coil and the latent heat of the refrigeration is removed as sensible heat by the air steam.

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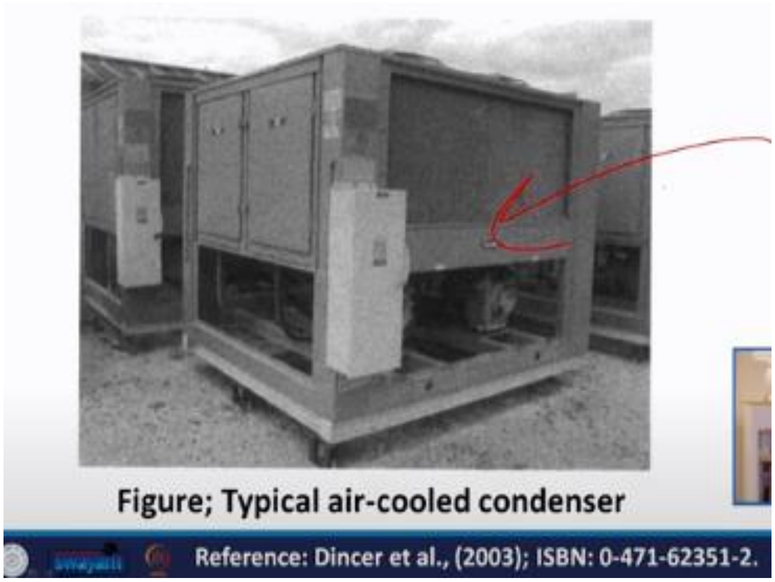

Now here you see this is the typical air-cooled condenser.

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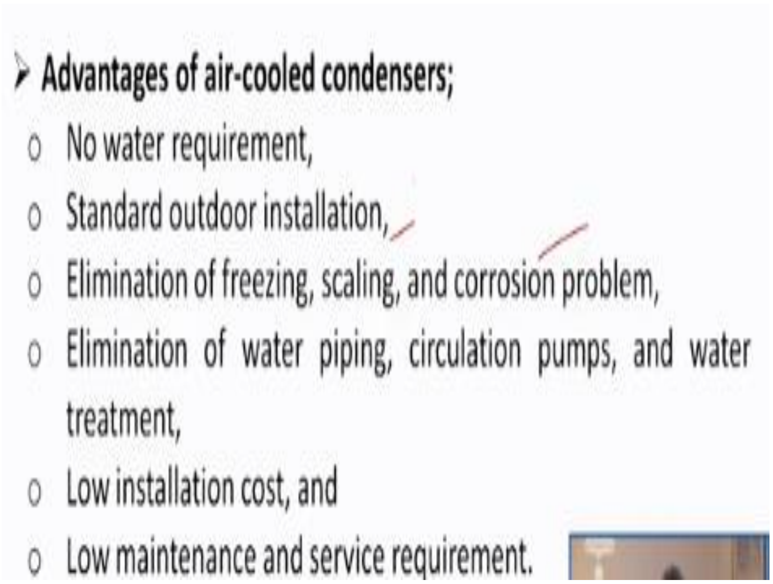

Now there are various advantages are associated with the air-cooled condenser one is that there is no requirement for water. Then we are having the standard outdoor installation, you can eliminate the freezing, scaling and corrosion problem. The elimination of water piping circulation pumps and water treatment etcetera they are not present. Low installation cost and apart from this because we are not addressing these kind of corrosion scaling etcetera problem then the cost of the maintenance and service requirement would be very low.

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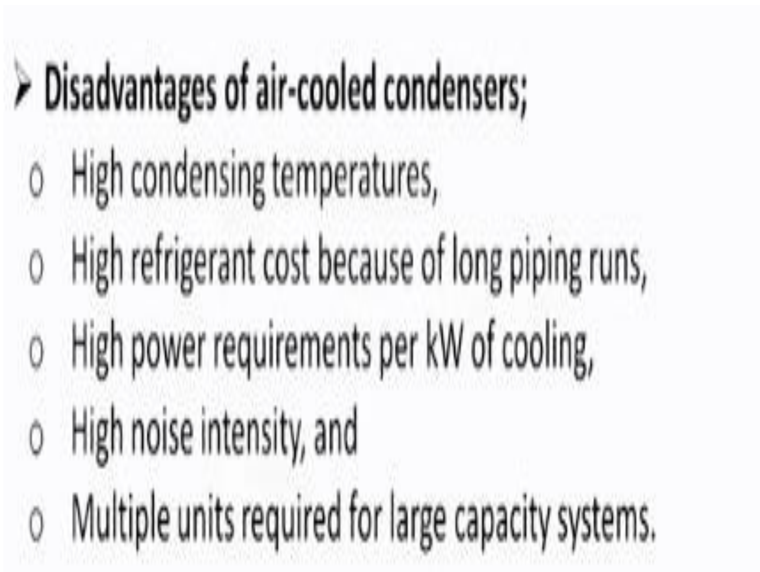

But simultaneously there are various disadvantages associated with air cooled condenser one is that the high condensing temperature, high refrigerant cost because of the long piping runs, high power requirement per kilowatt of cooling, high noise intensity, and multiple units required for the large capacity system.

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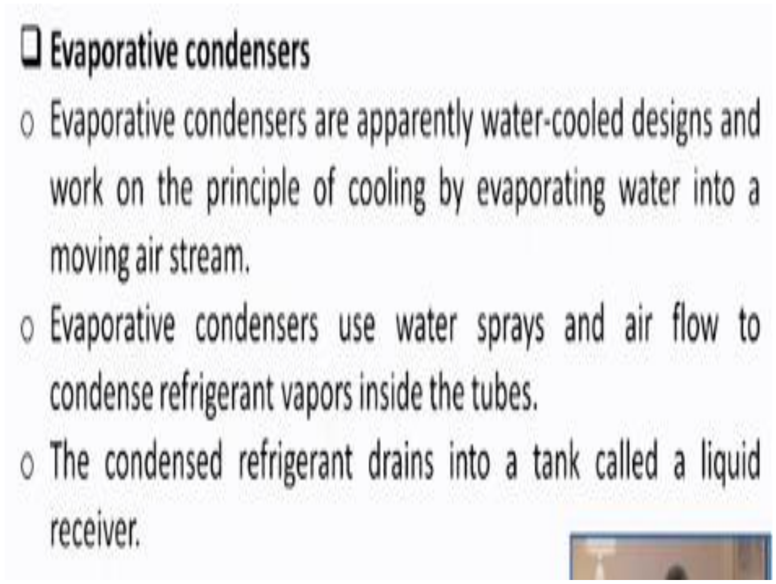

Now let us talk about the evaporative condensers, now evaporative condensers they are apparently water cooled designed and work on principle of cooling by evaporating water into a moving air system. Now evaporative condensers they use water sprays and air flow to condense the refrigerant vapor inside the tubes. The condensed refrigerant drains into a tank and that is called a liquid receiver.

Now refrigerant sub cooling this can be accomplished by piping the liquid from the receiver back through the water sump where additional cooling reduces the liquid temperature even further.

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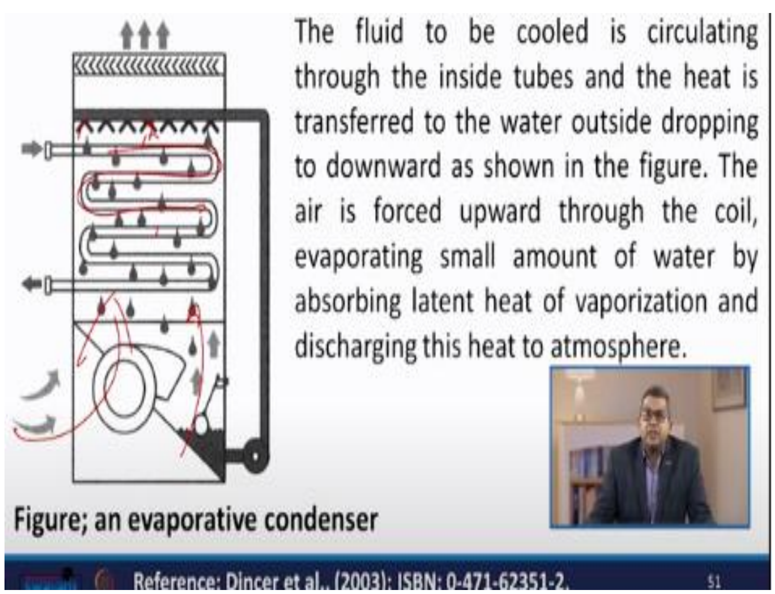

Now here you see this is the evaporative condenser here you see that the water is spray and droplets. Now the fluid to be cooled is circulating through the inside tubes and heat is transferred to the water outside dropping to the downward as per this figure. The air is forced upward through the coil and evaporating small amount of water by absorbing latent heat of vaporization and discharging this heat to the atmosphere.

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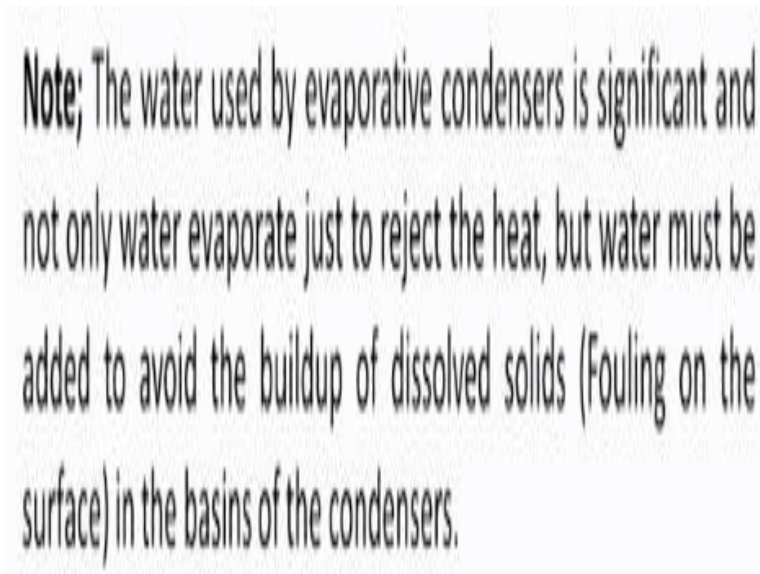

Now the water used by the evaporative condenser is significant and not only water evaporate just to reject the heat. But water must be added to avoid the buildup of dissolved solids falling on the surface or in the basin of the condenser.

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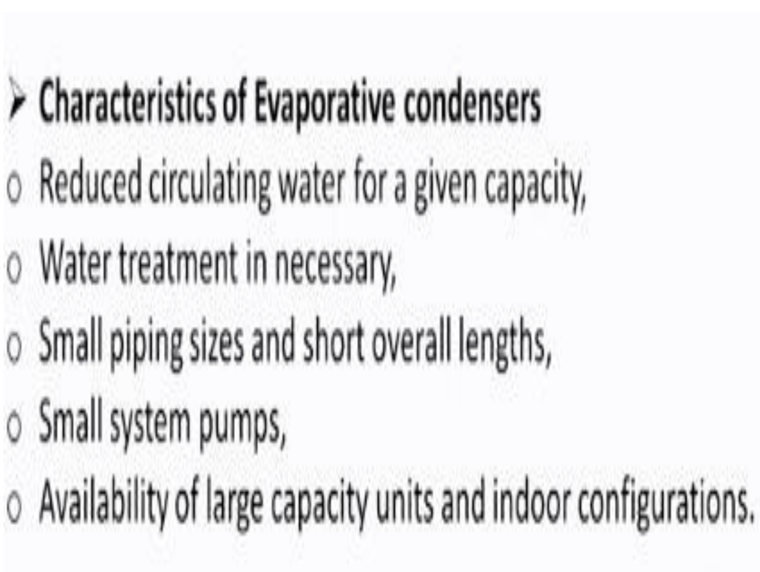

Now there are various characteristics of evaporative condenser one is that reduced circulating water for a given capacity, then water treatment is necessary every time. And small, piping sizes and short overall length the small system pumps availability of large capacity unit and indoor configuration. So, in this particular lecture we discussed about the various component of refrigeration's system.

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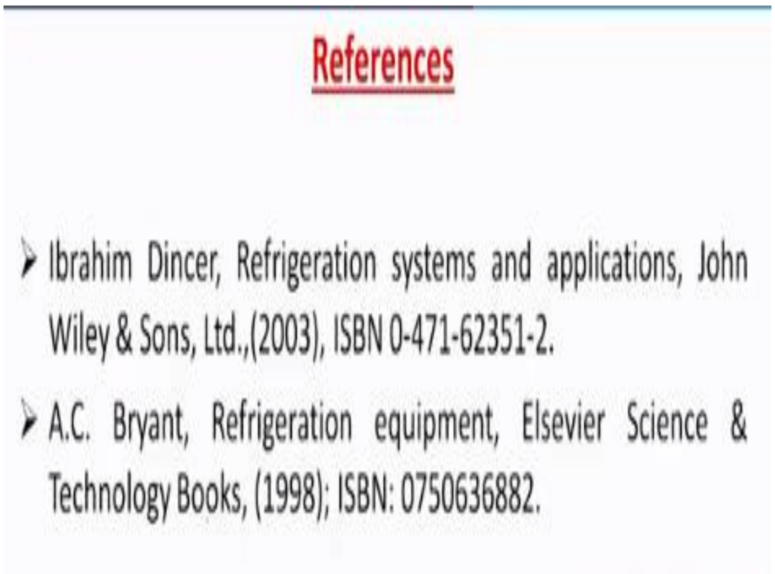

And if you need to have further study, we have enlisted couple of references for your convenience you can go through all these references if needed thank you very much.