Refrigeration and Air Conditioning

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Lecture No. # 26

Refrigeration Systems Component: Condensers

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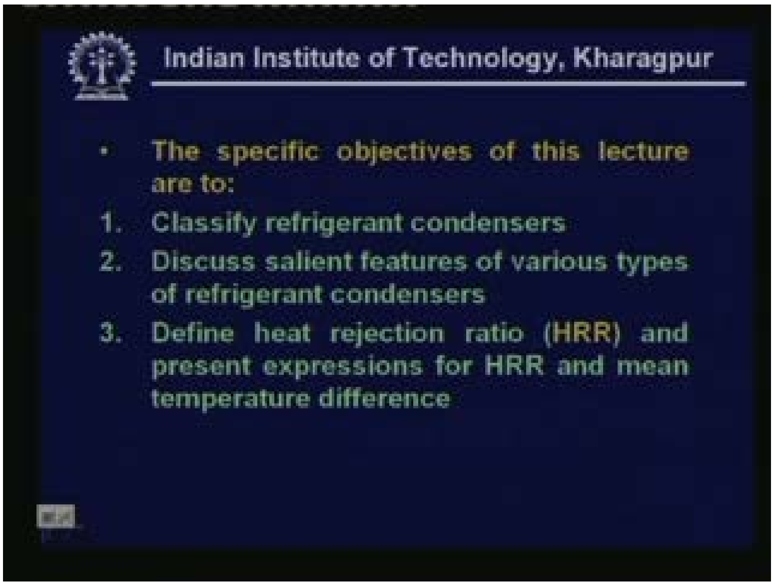

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- The specific objectives of this lecture are to:

1. Classify refrigerant condensers
2. Discuss salient features of various types of refrigerant condensers
3. Define heat rejection ratio (HRR) and present expressions for HRR and mean temperature difference

Welcome back the specific objectives of this particular lecture are to classify refrigerant condensers, discuss salient features of various types of refrigerant condensers, define heat rejection ratio and present expressions for heat rejection ratio and mean temperature difference.

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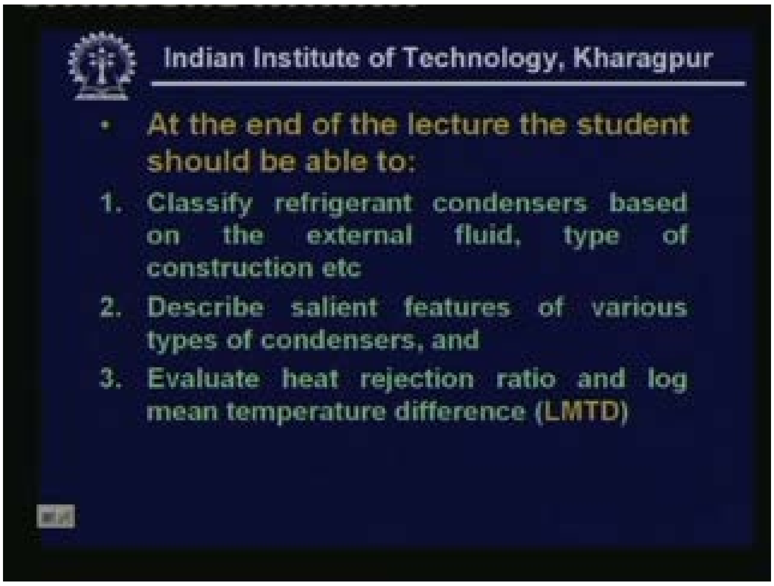

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- At the end of the lecture the student should be able to:

1. Classify refrigerant condensers based on the external fluid, type of construction etc
2. Describe salient features of various types of condensers, and
3. Evaluate heat rejection ratio and log mean temperature difference (LMTD)

At the end of the lecture you should be able to classify refrigerant condensers based on the external fluid type of construction etcetera. Describe salient features of various types of condensers and evaluate heat rejection ratio and log mean temperature difference LMTD of refrigerant condensers. Let me give a brief introduction here.

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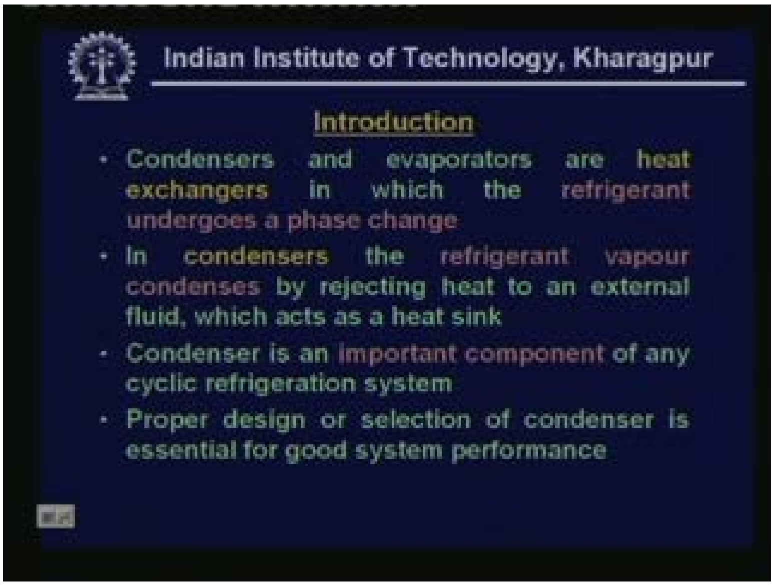

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Introduction

- Condensers and evaporators are heat exchangers in which the refrigerant undergoes a phase change
- In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink
- Condenser is an important component of any cyclic refrigeration system
- Proper design or selection of condenser is essential for good system performance

As you know condensers and evaporators are heat exchangers in which the refrigerant undergoes a phase change. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid which acts as a heat sink condenser is an important component of any cyclic refrigeration system. And proper design or selection of condenser is essential for good system performance.

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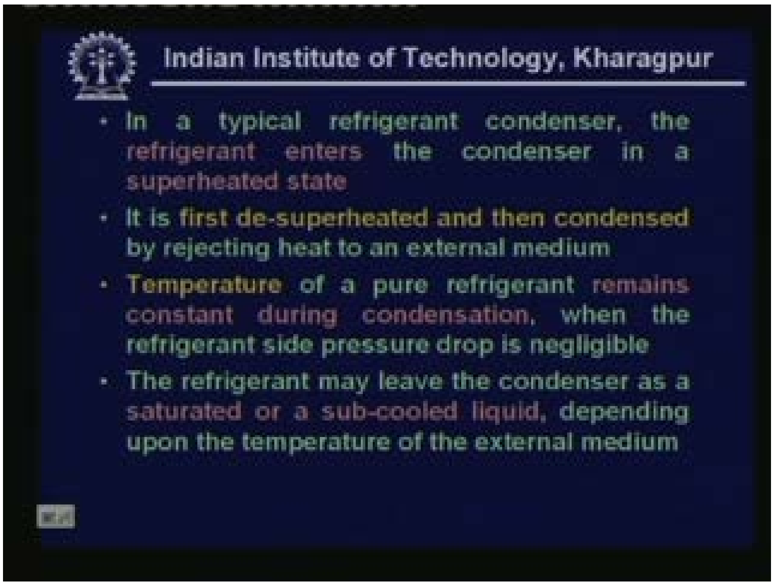

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- In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state
- It is first de-superheated and then condensed by rejecting heat to an external medium
- Temperature of a pure refrigerant remains constant during condensation, when the refrigerant side pressure drop is negligible
- The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium

In a typical refrigerant condenser the refrigerant enters the condenser in a superheated state it is first de-superheated. And then condensed by rejecting heat to an external medium temperature of a pure refrigerant remains constant during condensation when the refrigerant side pressure drop is negligible the refrigerant may leave the condenser as a saturated or a sub-cooled liquid depending upon the temperature of the external medium.

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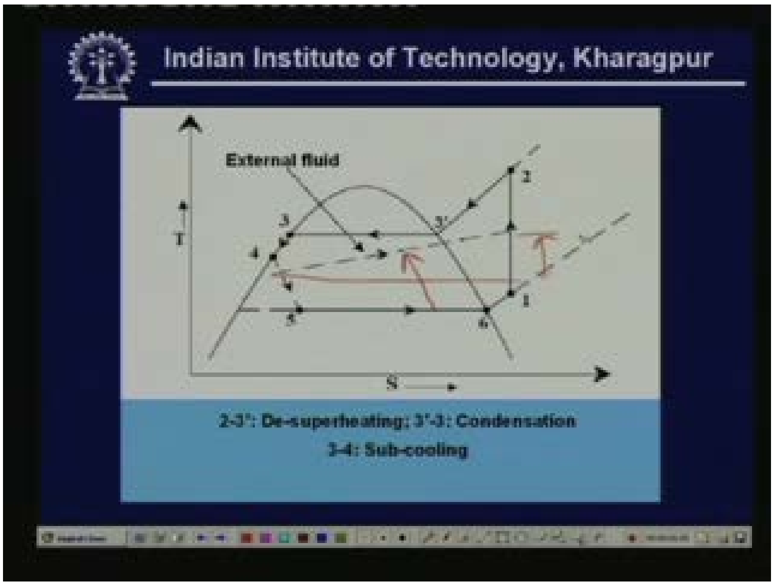
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2-3': De-superheating; 3'-3: Condensation
3-4: Sub-cooling

Now let me show the picture. You can see here the refrigeration cycle on TS diagram here the condensation process is as shown by three dash to three and the heat rejection in the condenser is shown by the process two to four this heat rejection consists of three different stages the first stage that is two to three dash is what is known as your de-superheating zone and three during which the pressure remains constant but the temperature varies from T two to T three dash which is nothing but the saturated temperature corresponding to the condenser pressure

and next stage is three dash to three which is nothing but the condensation phase during which both the temperature as well as the pressure of the refrigerant remain constant next you have the stage three to four which is a sub-cooling zone during which again the pressure remains constant but the temperature decreases from T three to T four

and in this picture you can also see the temperature profile of the external fluid so here it is external fluid flows in an opposite direction that means it’s a counter flow type of condenser so as the external fluid flows through the condenser its temperature increases because it takes the heat from the condensing refrigerant okay

Now the external fluid in most of the refrigerant refrigeration systems. The external fluid does not undergo any phase change okay. That means the heat transfer of as for the external fluid is concerned is sensible its temperature only increases. But it does not undergo any phase change. But there are some the special applications such as in a casket refrigeration systems, where the external fluid also undergoes a phase change right. But our discussion in this particular lecture is limited to an external fluid which does not undergo any phase change okay.

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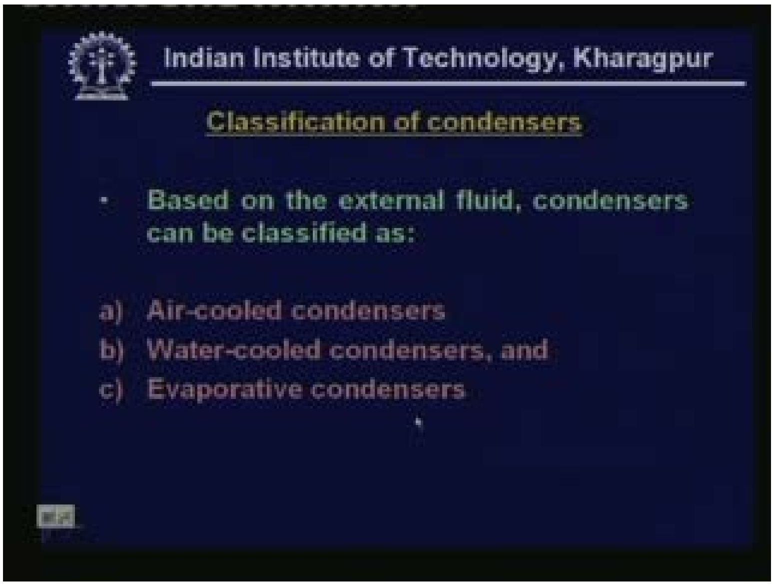

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Classification of condensers

- Based on the external fluid, condensers can be classified as:

a) Air-cooled condensers
b) Water-cooled condensers, and
c) Evaporative condensers

Now let us look at the classification of condensers based on the external fluid condensers can be classified as air-cooled condensers water-cooled condensers and evaporative condensers. Now let us look at each of these.

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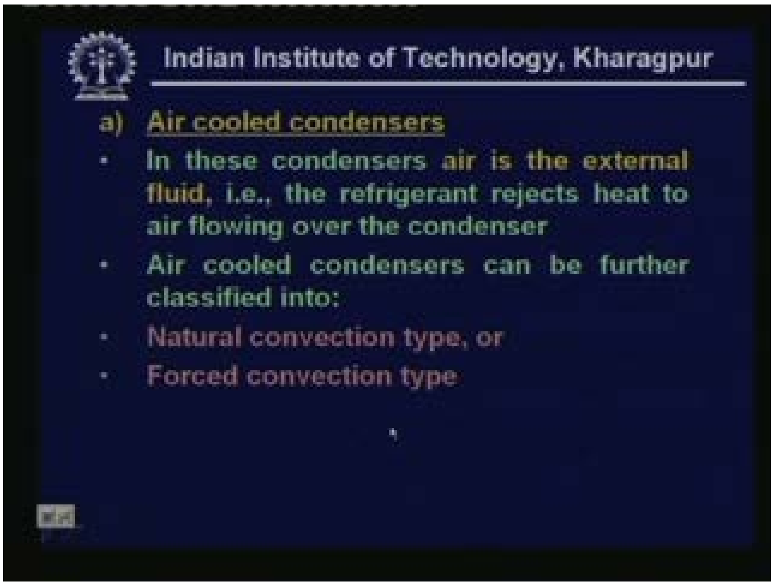

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a) Air cooled condensers

- In these condensers air is the external fluid, i.e., the refrigerant rejects heat to air flowing over the condenser
- Air cooled condensers can be further classified into:
- Natural convection type, or
- Forced convection type

First let us look at air cooled condenser as a name implies in an air cooled condenser air is the external fluid. That means the refrigerant rejects heat to air flowing over the condenser air cooled condensers can be further classified into natural convection type or forced convection type.

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Natural convection type

- Heat transfer from the condenser is by buoyancy induced natural convection and radiation
- Since the flow rate of air is small and the radiation heat transfer is also not very high, the combined heat transfer coefficient is small
- Hence a relatively large condensing surface is required to reject a given amount of heat
- Hence these are used for small capacity refrigeration systems like household refrigerators and freezers

Now let us look at natural convection type air cooled condenser here. The heat transfer from the condenser is by buoyancy induced natural convection and also by radiation since the flow rate of air is small due to the buoyancy. And the radiation heat transfer is also not very high the combined heat transfer coefficient of this kind of condensers is small. As a result you find that a relatively large condensing surface area is required to reject a given amount of heat. Hence these are used mainly for small capacity refrigeration systems such as household refrigerators and freezers.

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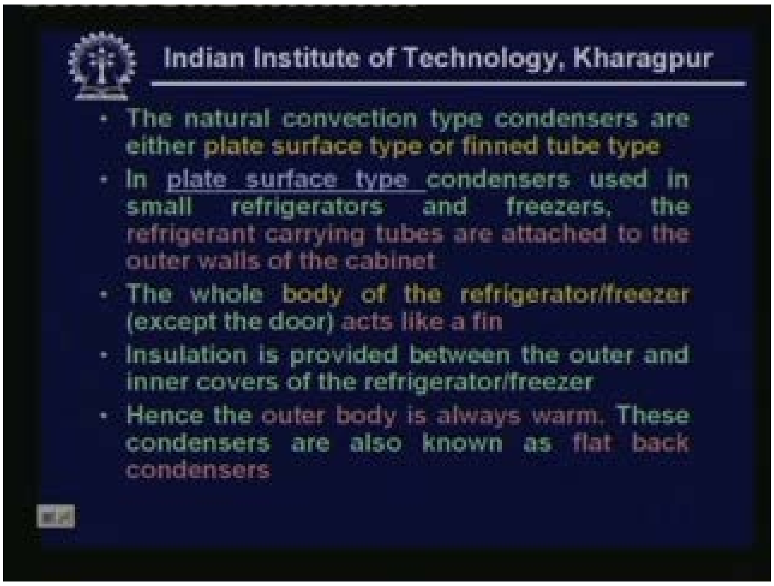

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- The natural convection type condensers are either plate surface type or finned tube type
- In plate surface type condensers used in small refrigerators and freezers, the refrigerant carrying tubes are attached to the outer walls of the cabinet
- The whole body of the refrigerator/freezer (except the door) acts like a fin
- Insulation is provided between the outer and inner covers of the refrigerator/freezer
- Hence the outer body is always warm. These condensers are also known as flat back condensers

The natural convection type condensers are either plate surface type or finned tube type. That means based on the construction you can again classify the natural convection type condensers as a plate surface type or fin tube type in plate surface type condensers. These are mainly used in small refrigerators and freezers the refrigerant carrying tubes are attached to the outer walls of the cabinet. The whole body of the refrigerator or freezer except the door acts like a fin and insulation is provided between the outer and inner covers of the refrigerator. Hence the outer body is always warm these condensers are also known as flat back condensers. Let me show a picture of this.

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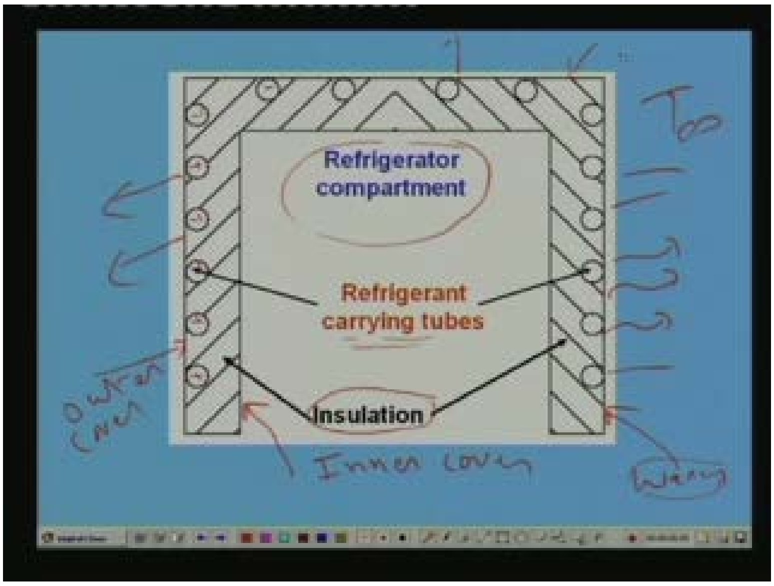

This picture shows the typical plate surface type of a condenser used in a domestic refrigerator. You can see here that this is the refrigerator compartment where the food products are stored okay. So this is the inner cover normally made of plastic this is the inner cover and this is the outer cover okay. Normally made of a metal okay. A metallic outer cover and the space between the inner and outer cover is filled with insulation normally. A polyurethane foam to reduce the heat leak from the outside to the refrigeration compartment okay.

And now the condenser tubes or the refrigerant carrying tubes are attached to the outer cover these are the refrigerant carrying tubes through which the refrigerant flows okay. So as the refrigerant flows it transfers heat first to the outer cover and from the outer cover heat is transferred to the surrounding air. That means the heat transfer takes place finally from the complete body of the refrigerator okay, to the surrounding air okay. So since the condensing temperature is always higher than the surrounding temperature you find that the outer surface of this kind of refrigerator is always warm okay. And this kind of condenser is also known as flat back type of condenser one advantage claimed for this kind of a condenser is that since the outer surface is warm there is no danger of water condensing on the outer surface okay.

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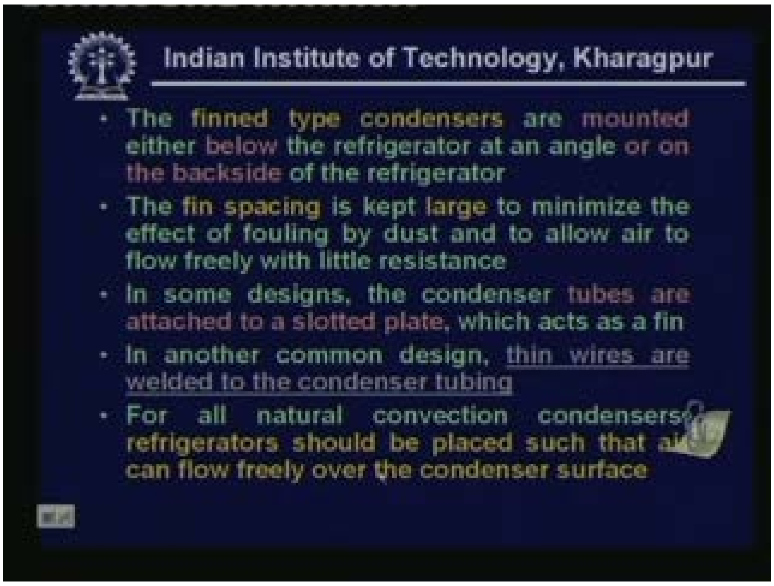

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- The finned type condensers are mounted either below the refrigerator at an angle or on the backside of the refrigerator
- The fin spacing is kept large to minimize the effect of fouling by dust and to allow air to flow freely with little resistance
- In some designs, the condenser tubes are attached to a slotted plate, which acts as a fin
- In another common design, thin wires are welded to the condenser tubing
- For all natural convection condensers refrigerators should be placed such that air can flow freely over the condenser surface

Now let us look at finned type of condensers the finned type of condensers are mounted either below the refrigerator at an angle. Or on the backside of the refrigerator the fin spacing is kept large to minimize the effect of fouling by dust. And to allow air to flow freely with little resistance this is required. Because you are relying on buoyancy induced effect in some designs. The condenser tubes are attached to a slotted plate which acts as a fin and in another common design thin wires are welded to the condenser tubing, this you must have seen in the older type of refrigerator. Let me show a picture of this.

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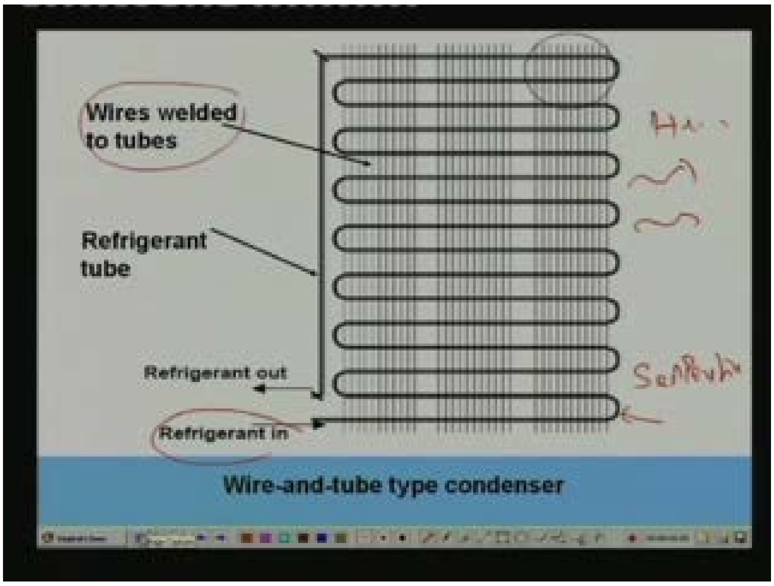

Wire-and-tube type condenser

This is what is known as wire and tube type of condenser. Here you can see that the condenser tubing the serpentine this is the serpentine condenser tubing through which the refrigerant flows okay. For example refrigerant enters at the bottom of the condenser it flows through the tube and as it flows through the tube it rejects heat to the surroundings okay. Heat rejection takes place to the surroundings and attached to these tubes or wires which are welded to these tubes. So these wires provide additional area and they act as fins. So heat transfer takes place not only from the refrigerant tubing. But also from these wires and this whole assembly is kept at the backside of the domestic refrigerator. For all natural convection type of condensers refrigerators should be placed such that air can flow freely over the condenser surface. So you have to orient it properly. So that proper air flow can be maintained.

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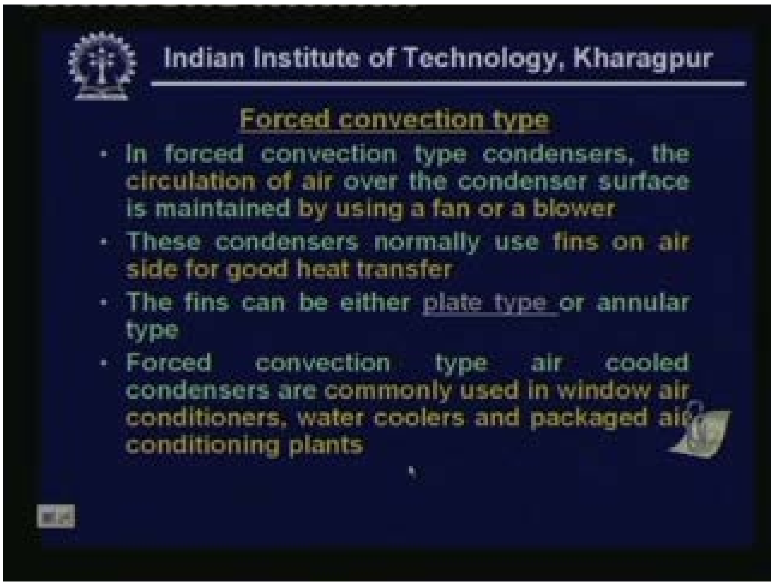

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Forced convection type

- In forced convection type condensers, the circulation of air over the condenser surface is maintained by using a fan or a blower
- These condensers normally use fins on air side for good heat transfer
- The fins can be either plate type or annular type
- Forced convection type air cooled condensers are commonly used in window air conditioners, water coolers and packaged air conditioning plants

Now let us look at forced convection type of air cooled condensers in forced convection type condensers. The circulation of air over the condenser surface is maintained by using a fan or a blower okay. That means you use an external device for maintaining the air flow. These condensers normally use fins on air side for good heat transfer the fins can be either plate type or annular type.

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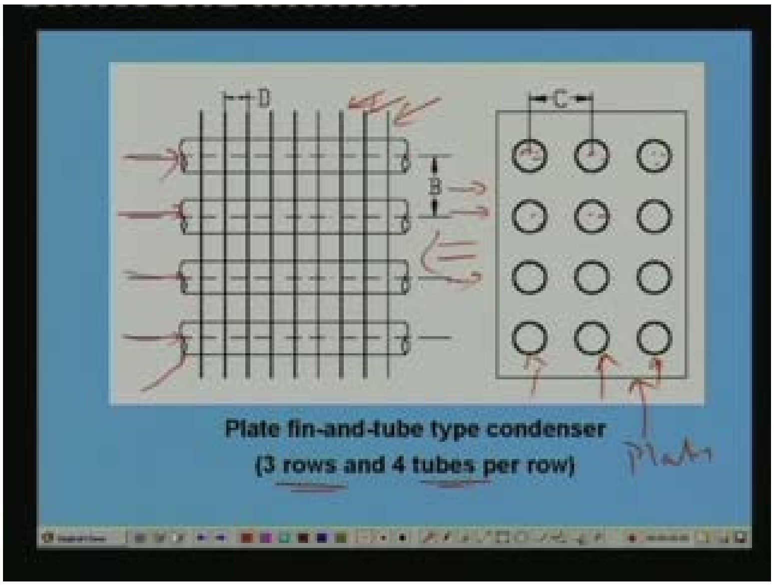

Plate fin-and-tube type condenser

(3 rows and 4 tubes per row)

So let me show the picture of a plate type of, so this is what is known as plate fin-and-tube type of condenser. So here again you can see the tubes okay these are the tubes through which refrigerant flows okay. And through to these tubes plates are attached. These are the plates which are attached to these tubes and if you see from the side the side view is something like this. You can see that this is the plate okay. And these are the tubes through which the refrigerant flows okay. So here if let us say that air also flows in this direction okay. Then there are number of rows in the air flow direction. For example there are three tubes in the air flow direction. So you call this as three row type of condenser and for each row there are four tubes okay. So this is what is known as your plate fin-and-tube type of condenser.

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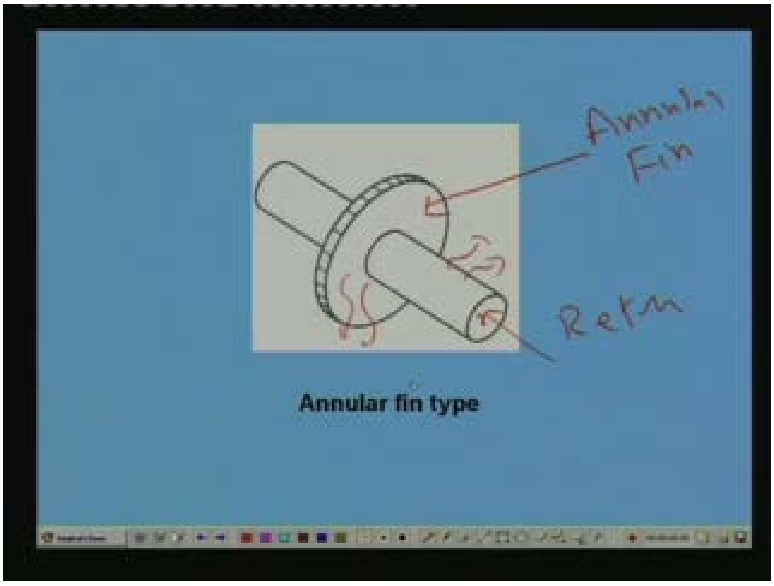

Annular fin type

Next this is annular fin type. That means you have again a tube through which refrigerant flows okay. And you also have an annular fin okay so annular fin is attached to this tube. So heat transfer takes place from the bear surface of the tube and also from the surface of the fin okay. So this kind of condenser is known as annular fin type of condenser forced convection type air cooled condensers are commonly used in window air conditioners water coolers and packaged air conditioning plants.

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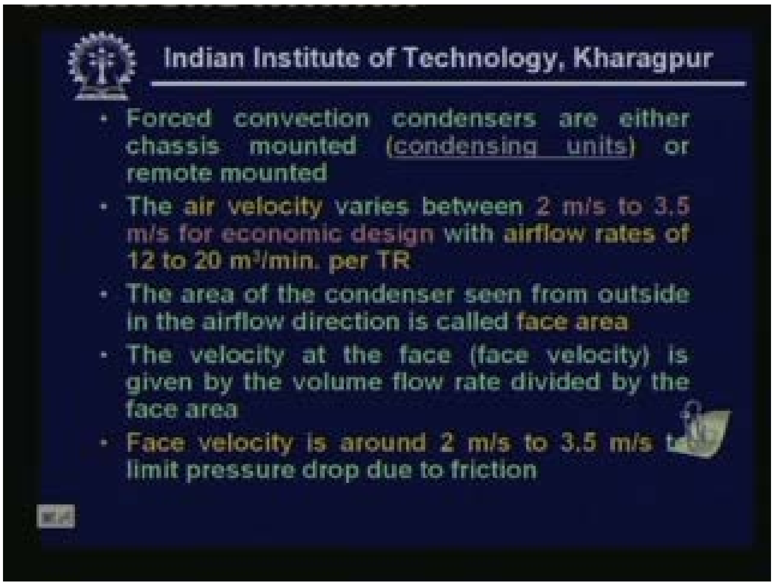

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- Forced convection condensers are either chassis mounted (condensing units) or remote mounted
- The air velocity varies between 2 m/s to 3.5 m/s for economic design with airflow rates of 12 to 20 m^3/min. per TR
- The area of the condenser seen from outside in the airflow direction is called face area
- The velocity at the face (face velocity) is given by the volume flow rate divided by the face area
- Face velocity is around 2 m/s to 3.5 m/s to limit pressure drop due to friction

Forced convection condensers are either chassis mounted. So these are called as condensing units or remote mounted. So what is the condensing unit?

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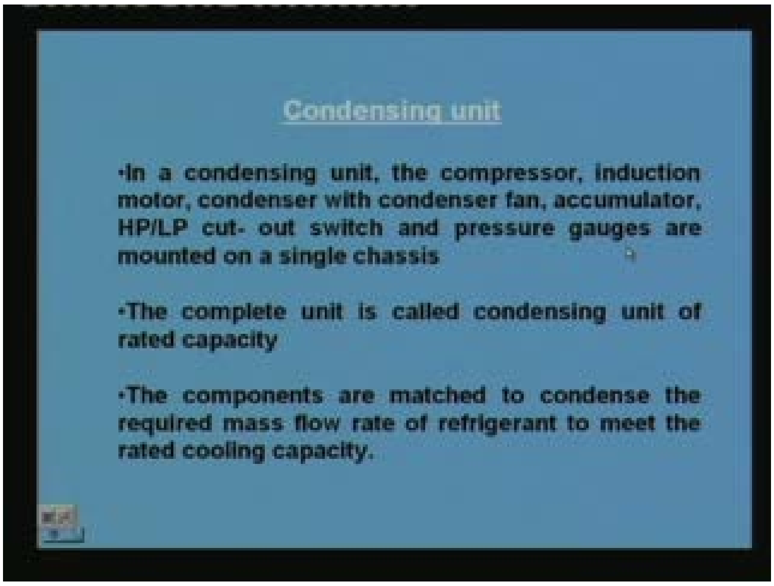

Condensing unit

- In a condensing unit, the compressor, induction motor, condenser with condenser fan, accumulator, HP/LP cut- out switch and pressure gauges are mounted on a single chassis
- The complete unit is called condensing unit of rated capacity
- The components are matched to condense the required mass flow rate of refrigerant to meet the rated cooling capacity.

In a condensing unit the compressor induction motor condenser with condenser fan accumulator high pressure low pressure cut-out switch. And pressure gauges are mounted on a single chassis and this complete unit is called as condensing unit of rated capacity. The components are matched to condense the required mass flow rate of the refrigerant to meet the rated cooling capacity. So this is known as a condensing unit in fact these condensing units are available off the self. That means if you want a condensing unit let us say for a three turn refrigeration plant then you can straight away buy a three turn refrigeration plant condensing unit which consist of the compressor condenser the controls motors etcetera. So all that you have to do is you would have you have to connect a suitable evaporator and expansion device to this condensing unit. So that you can have the complete system okay. So this is very advantageous in especially in smaller systems for quick assembly. Because you do not have to match the components that means match compressor with condenser motor with compressor etcetera.

That will be done by the manufacturer himself okay. So all that you have to do is you have to specify the refrigeration capacity and buy a suitable condensing unit and then assemble the condensing unit to the evaporator and expansion device okay. The air normally the air velocity varies between two metre per second to three point five metre per second for economic design and the air flow rates varies between twelve to twenty metre cube per minute per ton of refrigeration. The area of the condenser seen from outside in the airflow direction is called as face area the velocity at the face also known as face velocity is given by the volume flow rate divided by the face area. Face velocity is around two metre per second to three point five metre per second to limit pressure drop due to friction.

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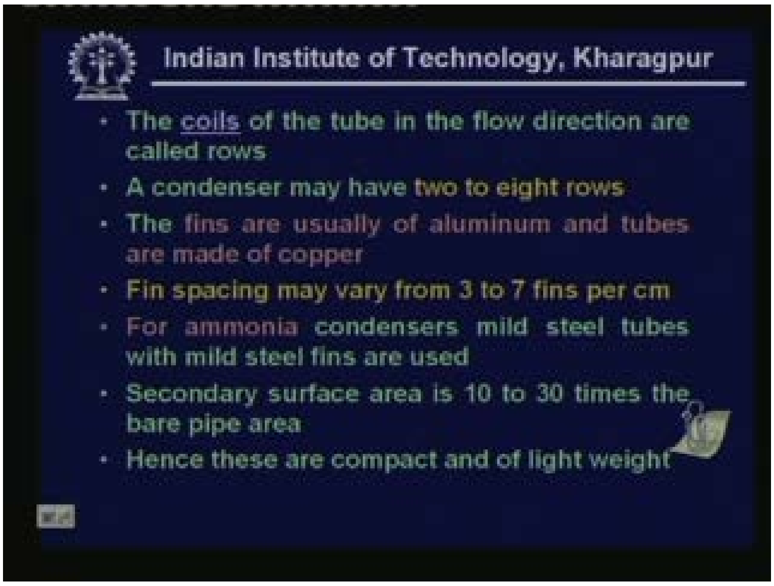

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- The coils of the tube in the flow direction are called rows
- A condenser may have two to eight rows
- The fins are usually of aluminum and tubes are made of copper
- Fin spacing may vary from 3 to 7 fins per cm
- For ammonia condensers mild steel tubes with mild steel fins are used
- Secondary surface area is 10 to 30 times the bare pipe area
- Hence these are compact and of light weight

The coils of the tubes, I have already mentioned the coils of the tube in the flow direction are called as rows and a condenser may have two to eight rows the fins are usually of aluminium and tubes are made of copper and fins spacing may vary from three to seven fins per centimetre. For ammonia condensers, since ammonia is not compatible with copper mild steel tubes are used with mild steel fins secondary surface area in all these force convection type of evaporators or condensers the secondary surface area that is the surface area of the finned surfaces is about ten to thirty times that of the bare pipe area okay. So you get a large effective surface area as a result these type of condensers or evaporators are very compact and of light weight this is an advantage of a forced convection type of heat exchangers.

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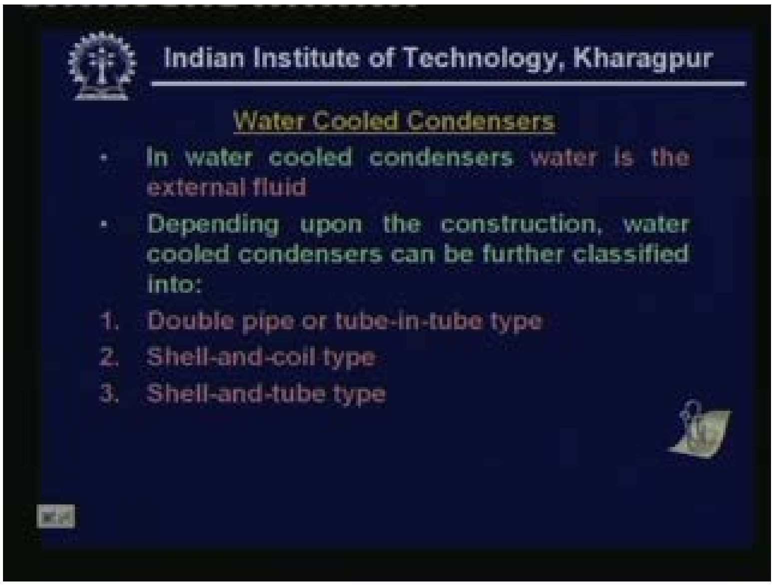

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Water Cooled Condensers

- In water cooled condensers water is the external fluid
- Depending upon the construction, water cooled condensers can be further classified into:

1. Double pipe or tube-in-tube type
2. Shell-and-coil type
3. Shell-and-tube type

Now let us look at water cooled type of condensers in water cooled condensers. As the name implies water is the external fluid and depending upon the construction water cooled condensers can be further classified into double pipe or tube-in-tube type shell-and-coil type and shell-and-tube type.

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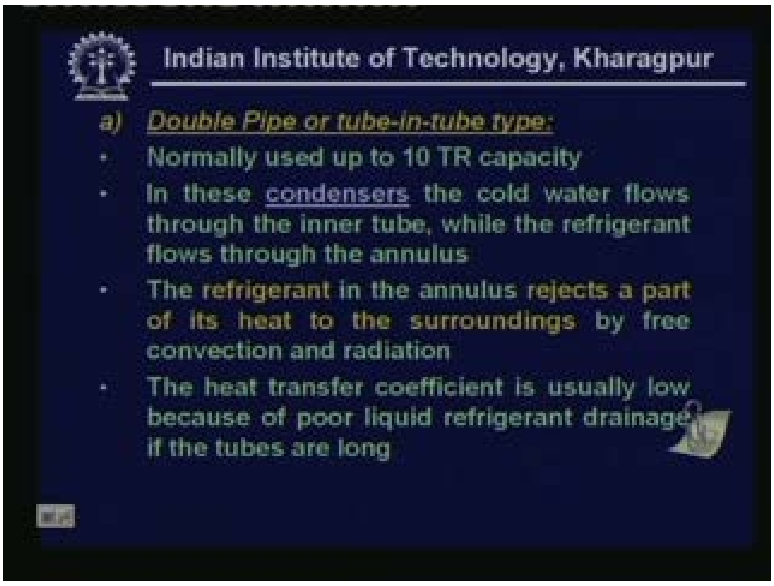

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a) *Double Pipe or tube-in-tube type:*

- Normally used up to 10 TR capacity
- In these condensers the cold water flows through the inner tube, while the refrigerant flows through the annulus
- The refrigerant in the annulus rejects a part of its heat to the surroundings by free convection and radiation
- The heat transfer coefficient is usually low because of poor liquid refrigerant drainage if the tubes are long

Now let us look at double pipe or tube-in-tube type these type of condensers are normally used up to ten ton of capacity. In these condensers the cold water flows through the inner tube while the refrigerant flows through the annulus. The refrigerant in the annulus rejects a part of its heat to the surroundings by free convection and radiation. And the heat transfer coefficient in these kind of condenser is typically low. Because of poor liquid refrigerant drainage if the tubes are long. Now let me show a picture of this double pipe type of condenser.

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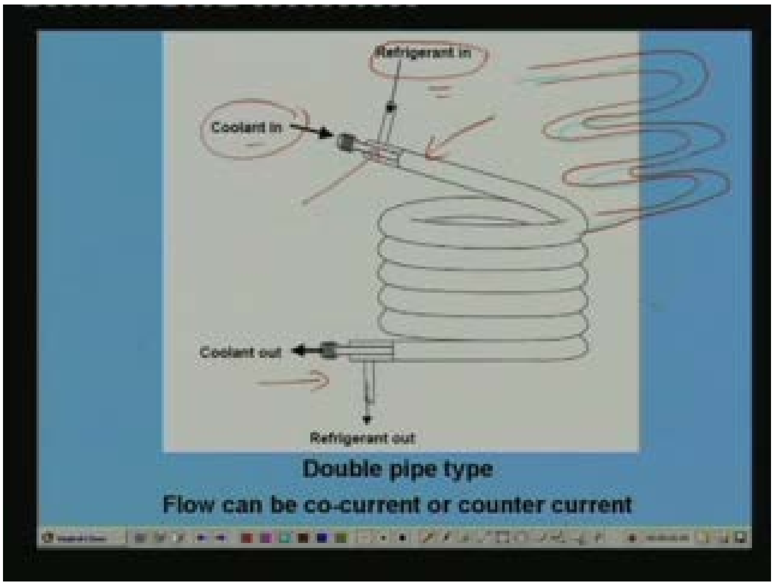

Double pipe type

Flow can be co-current or counter current

This shows a typical double pipe type of a condenser which is formed in a which is made in the form of a coil okay. So here you can see this is the inner tube okay, through which the coolant flows okay. And this is the outer tube and the refrigerant flows through the space between the inner and outer tube. That means through the annular space. In this particular picture the direction of the coolant and refrigerant are parallel. That means this is a parallel flow type. But in general you can also have counter current type. That means refrigerant enters in the top and coolant enters from the bottom. That means flow can be either counter current or co-current okay. And it is not necessary that you have to make this in the form of a coil you can also have this a in this form okay. So you can have tubing okay. Let us say that you have the outer tube like this okay. And the inner tube can be the inner tube will be something like this okay.

And you can also many rows. That means you can have one row behind the other like that as I was telling in these type of condensers the heat transfer coefficient is relatively low. Because the refrigerant that is flowing here condenses and we will see later that the heat transfer coefficient depends upon how fast the condensate drains out. So if the tube is very long then the drainage takes place very inefficiently. As a result you will find that the heat transfer coefficient on the refrigerant side is small.

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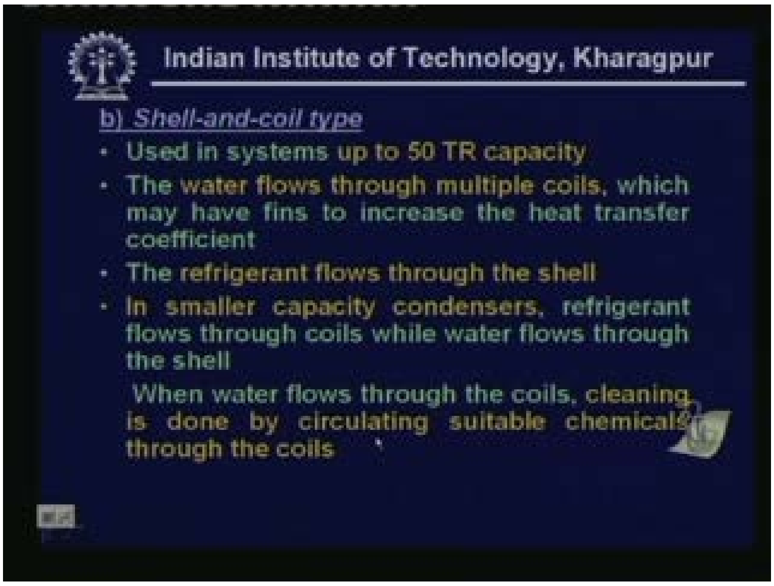

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b) *Shell-and-coil type*

- Used in systems up to 50 TR capacity
- The water flows through multiple coils, which may have fins to increase the heat transfer coefficient
- The refrigerant flows through the shell
- In smaller capacity condensers, refrigerant flows through coils while water flows through the shell

When water flows through the coils, cleaning is done by circulating suitable chemicals through the coils

Now let us look at shell-and-coil type these type of condensers are used in systems up to fifty ton capacity the water flows through multiple coils which may have fins to increase the heat transfer coefficient the refrigerant flows through the shell. However in small capacity condensers the refrigerant flows through coils while water flows through the shell when water flows through the coils cleaning is done by circulating suitable chemicals through the coils. Let me show a picture of shell-and-coil type.

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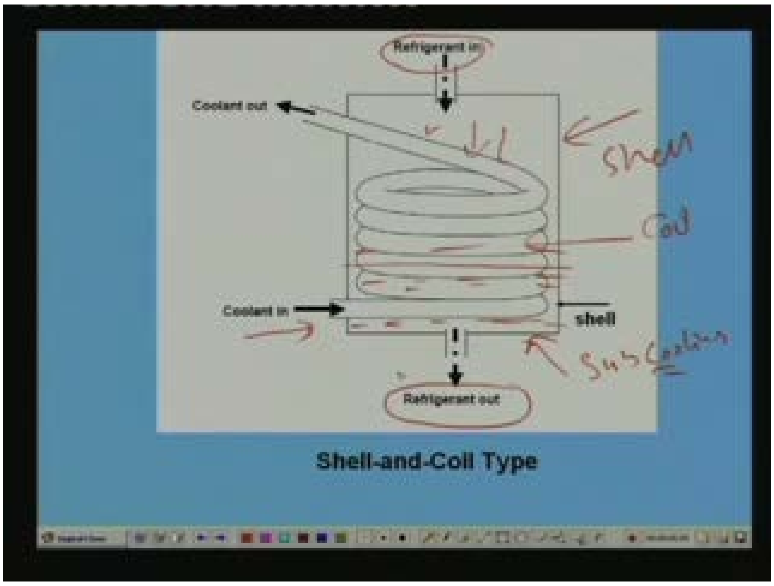

Shell-and-Coil Type

So you can see the shell-and-coil type of condenser. Here as you can see here this is the, your shell okay. So refrigerant vapour enters at the top it comes in contact with the coil. So this is your coil okay. Through the coil the coolant flows in this case the coolant enters at the bottom and leaves on the top. So the coolant flows through the coil and the refrigerant vapour comes in contact with the coil. As it comes in contact with the coil it rejects heat to the coolant and it condenses. And condenser drains out and you'll find that the condenses gets collected at the bottom okay. And finally it drains out from the bottom okay.

Since the coolant is entering at the bottom there is a possibility of having some sub-cooling. Because the coldest part of the coolant comes in contact with the refrigerant that is leaving the shell. So you can have some kind of a, some amount of sub-cooling okay. So which will improve the performance. As I said if the refrigerant flow rate is small then having the refrigerant on the shell side will not give you sufficient heat transfer coefficient okay. In such cases when you have small refrigerant flow the refrigerant will be on the coil side where as the coolant will be on the shell side okay.

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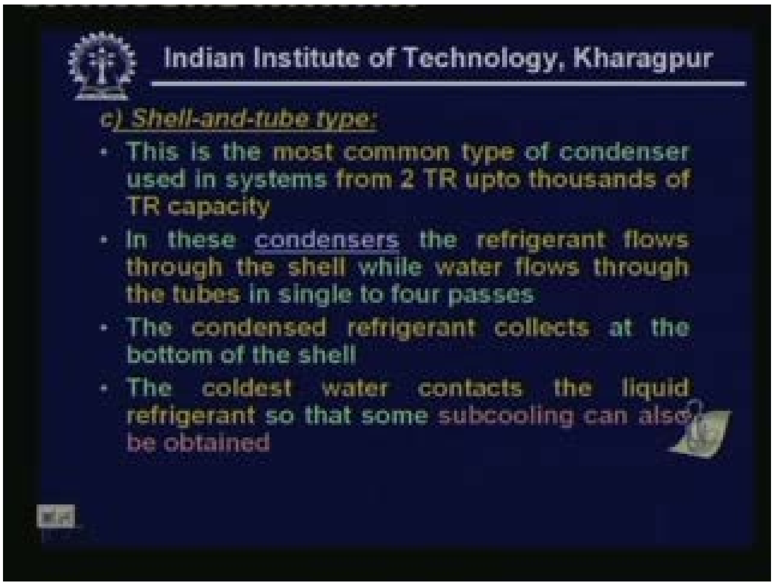

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c) Shell-and-tube type:

- This is the most common type of condenser used in systems from 2 TR upto thousands of TR capacity
- In these condensers the refrigerant flows through the shell while water flows through the tubes in single to four passes
- The condensed refrigerant collects at the bottom of the shell
- The coldest water contacts the liquid refrigerant so that some subcooling can also be obtained

Now let us look at the third type. That is shell-and-tube type condenser, this is the most common type of condenser and it is used in capacities varying from two tons up to thousands of tons. In these condensers the refrigerant flows through the shell while water flows through the tubes in single to four passes the condensed refrigerant collects at the bottom of the shell the coldest water contacts the liquid refrigerant. So that some of cooling can also be obtained let me show a picture of a typical shell-and-tube type of condenser.

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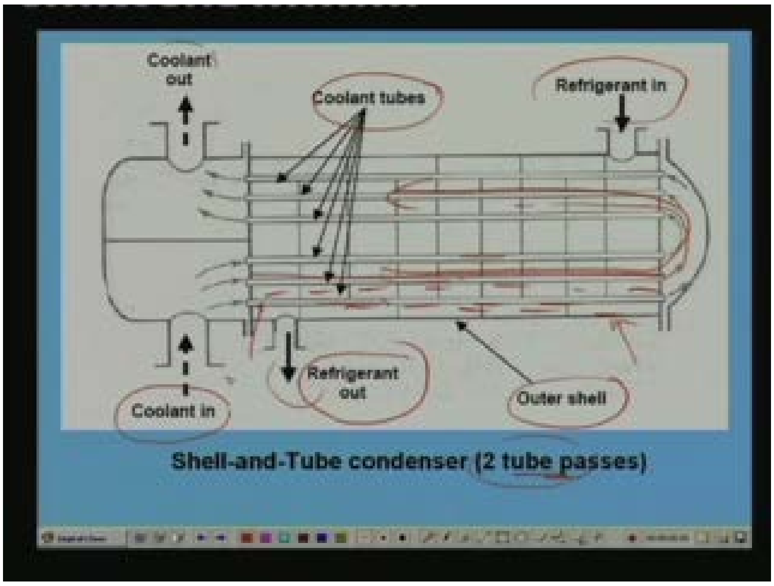

Shell-and-Tube condenser (2 tube passes)

You can see here shell-and-tube condenser with two tube passes what is the meaning of tube passes. Let me explain the construction details you have the outer shell here okay. So refrigerant vapour which flows through the shell enters at the top okay. And leaves from the bottom and this shell consists of several tubes okay. So these are the tubes you can see the coolant tubes. And through this coolant tubes the coolant flows in this kind of an arrangement the coolant enters at the bottom flows the through all these tubes okay. Since it is two tube pass the coolant flows through the condenser twice. That means first it flows like this and then from the end plate again it flows through the condenser okay. So that means it enters like this and again it flows like this. So it crosses the refrigerant twice. So you call this as twice tube pass type of condenser okay. So as the refrigerant vapour comes in contact with the coolant through which the coolant is flowing.

Again heat rejection from the refrigerant takes place. So refrigerant condenses and the condensed refrigerant again collects at the bottom of the shell okay. And finally this condensed refrigerant leaves from the bottom okay. Typically when you, whenever you are using shell-and-tube type of a condenser this refrigerant goes to a receiver from where it goes to the expansion device. Since the coolant is again entering at the bottom and its temperature at the bottom is very less compared to the coolant leaving temperature. There is a possibility of some sub-cooling of the refrigerant okay. Because the refrigerant leaving the condenser comes in contact with the coolant at the lowest temperature okay.

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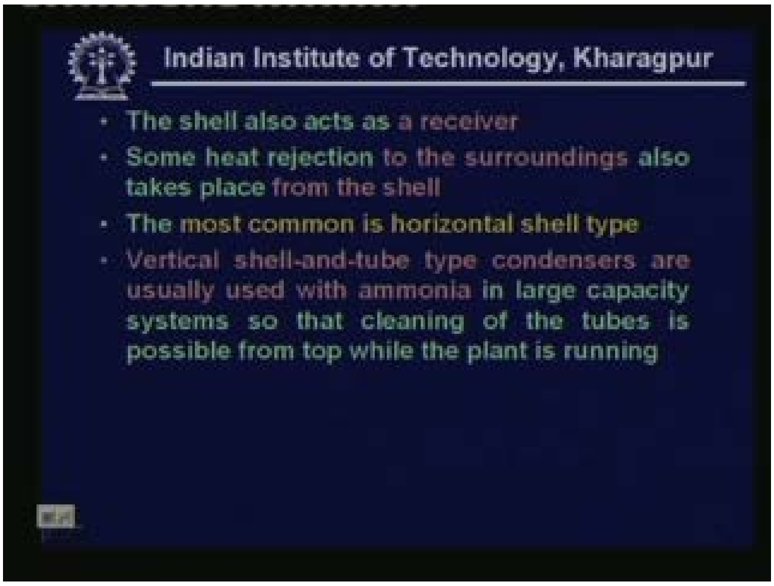

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- The shell also acts as a receiver
- Some heat rejection to the surroundings also takes place from the shell
- The most common is horizontal shell type
- Vertical shell-and-tube type condensers are usually used with ammonia in large capacity systems so that cleaning of the tubes is possible from top while the plant is running

Now some heat rejection also takes place from the shell and the shell also acts as a receiver. So as I said heat rejection to the surroundings also takes place from the shell. So shell is not insulated the most common type of shell-and-tube type of condenser is of horizontal shell type. That means the orientation is horizontal. Of course you can also have vertical shell-and-tube of tube type of condensers which are commonly used with ammonia in large capacity systems. So the advantage of vertical shell-and-tube type of condensers is that since the water flows through the tubes and if the water quality is not very good then after sometime fouling occurs on the water side okay. So the tubes require continuous cleaning okay. So if the condenser is vertical then without shutting down the plant you can clean the tubes from the top okay. So this is the advantage of vertical shell-and-tube type of condensers which are normally used with ammonia okay.

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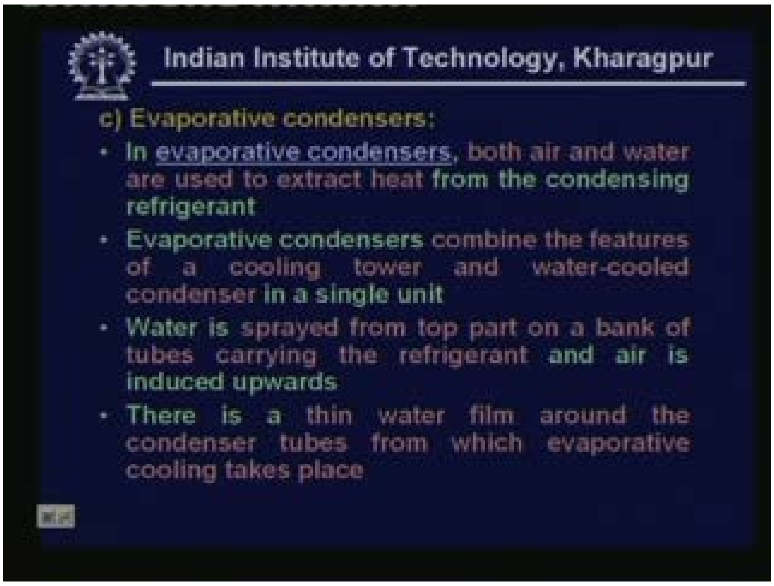

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c) Evaporative condensers:

- In evaporative condensers, both air and water are used to extract heat from the condensing refrigerant
- Evaporative condensers combine the features of a cooling tower and water-cooled condenser in a single unit
- Water is sprayed from top part on a bank of tubes carrying the refrigerant and air is induced upwards
- There is a thin water film around the condenser tubes from which evaporative cooling takes place

Now let us look at evaporative condenser in evaporative condensers. Both air and water are used to extract heat from the condensing refrigerant evaporative condensers combine the features of a cooling tower and a water-cooled condenser in a single unit. Water is sprayed from top part on a bank of tubes carrying the refrigerant. And air is induced upwards there is a thin water film around the condenser tubes from which evaporative cooling takes place. So now let me explain the working principle of evaporative condenser.

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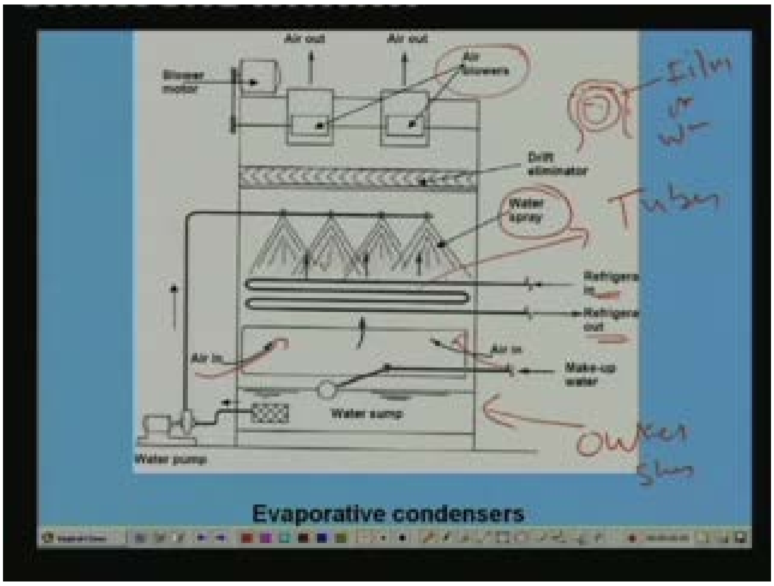

Evaporative condensers

This picture here shows a typical evaporative condenser. So what you have here is refrigerant tubing okay. So this is the refrigerant tubes. So refrigerant enters this tubes and it flows through the tube and it leaves form the, a bottom okay. And this entire refrigerant tube, tubing is kept in an outer let say that an outer shell and water is sprayed you can see that water is sprayed on to these tubes. And when water is sprayed on to these tubes a thin water film forms around the let us say this is your condenser tubing. So outside the condenser tube a thin film of water forms okay so this is the film of water okay. And simultaneously some air is induced. You can see that at the top of the evaporative condenser. You have air blowers which induce air flow.

So air is taken in from the bottom okay. So air flows first over the refrigerant tubing then it comes in contact with the water spray. So when air comes in contact with water spray they'll be some evaporative cooling. That means if the air is not saturated then some water from the water spray evaporates okay. That means you have heat transfer both latent as well as sensible from the water okay. So as a result the water temperature drops. So the water finally that is coming on to the tube surface of the refrigerant has a temperature lower than that of the drivel temperature of air okay. It will in fact, it will be closer to the wet bulb temperature of the air okay. So you can see that since the water temperature. That means the film of water has a much lower temperature than the drivel temperature of air the heat transfer will be very effective okay.

Finally the air leaves from the top and you have drift eliminators which will prevent the exit of water droplets along with the air okay. So the water droplets are arrested here and they fall back. So waterfalls here is collected in the water sump and again the same water is pumped to the top and from the top you have nozzles from which the water is sprayed on to the refrigerant tubing okay. Whatever you do there will be some amount of water loss here. Because of the evaporation of water. So you have to continuously supply some amount of makeup water okay. The makeup water is supplied to this tank or the to the water sump using a float type of valve okay. So this is a typical evaporative condenser.

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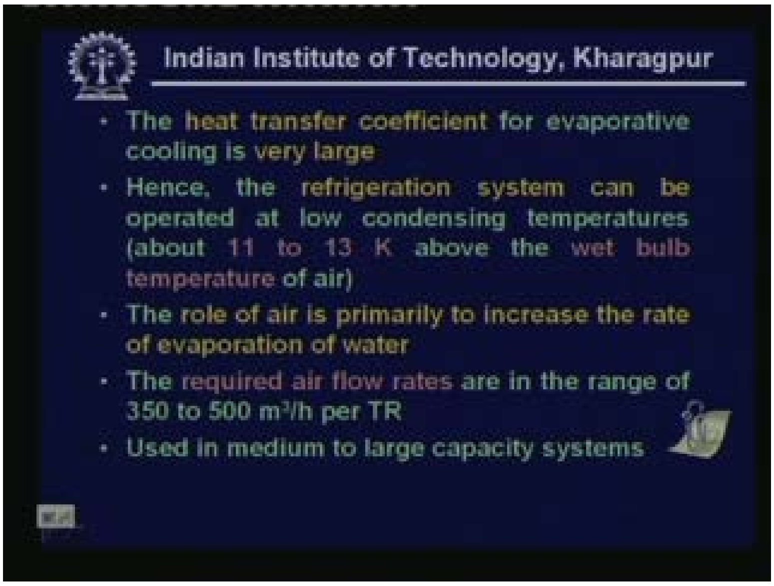

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- The heat transfer coefficient for evaporative cooling is very large
- Hence, the refrigeration system can be operated at low condensing temperatures (about 11 to 13 K above the wet bulb temperature of air)
- The role of air is primarily to increase the rate of evaporation of water
- The required air flow rates are in the range of 350 to 500 m^3/h per TR
- Used in medium to large capacity systems

Now the heat transfer coefficient for evaporative cooling is very large. Because here the heat transfer takes place both sensibly as well as by latent heat transfer mode. Hence the refrigeration system can be operated at low condensing temperatures. Typically the condensing temperatures will be about eleven to thirteen Kelvin above the wet bulb temperature of air this is important. So this is the wet bulb temperature of air and the role of air is primarily to increase the rate of evaporation of water okay. So heat transfer from refrigerant to air is not so very high but the air primarily takes part in evaporative cooling of the water okay.

And the required air flow rates are in the range of three fifty to five hundred metre cube per hour per ton of refrigeration. And these evaporative condensers are mainly used in medium to large capacity systems.

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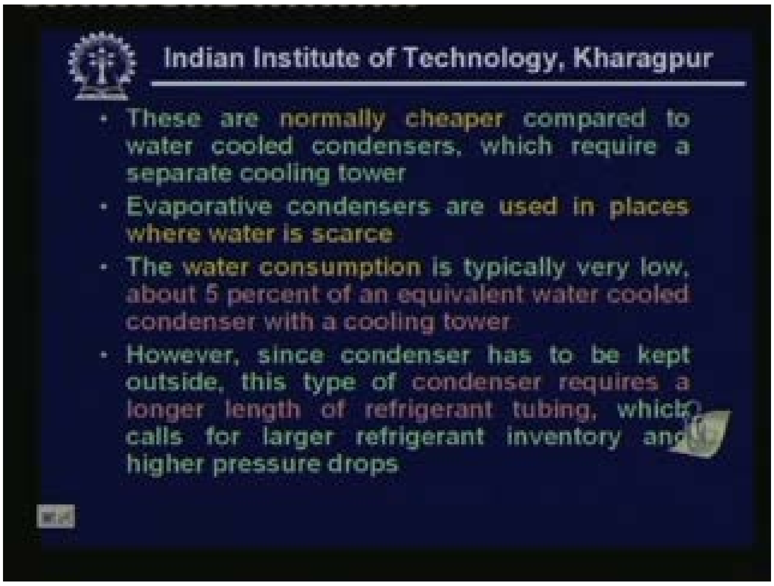

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- These are normally cheaper compared to water cooled condensers, which require a separate cooling tower
- Evaporative condensers are used in places where water is scarce
- The water consumption is typically very low, about 5 percent of an equivalent water cooled condenser with a cooling tower
- However, since condenser has to be kept outside, this type of condenser requires a longer length of refrigerant tubing, which calls for larger refrigerant inventory and higher pressure drops

And these are normally cheaper compared to water cooled condensers which requires a separate cooling tower. And evaporative condensers are used in places where water is scarce. This is because you will find that in evaporative condensers the water consumption is typically very low. That means about five percent of an equivalent water cooled condenser with a cooling tower. However the disadvantage of evaporative condenser is that since condenser has to be kept outside this type of condenser requires a longer length of refrigerant tubing which calls for larger refrigerant inventory and higher pressure drops. So this is an a disadvantage okay.

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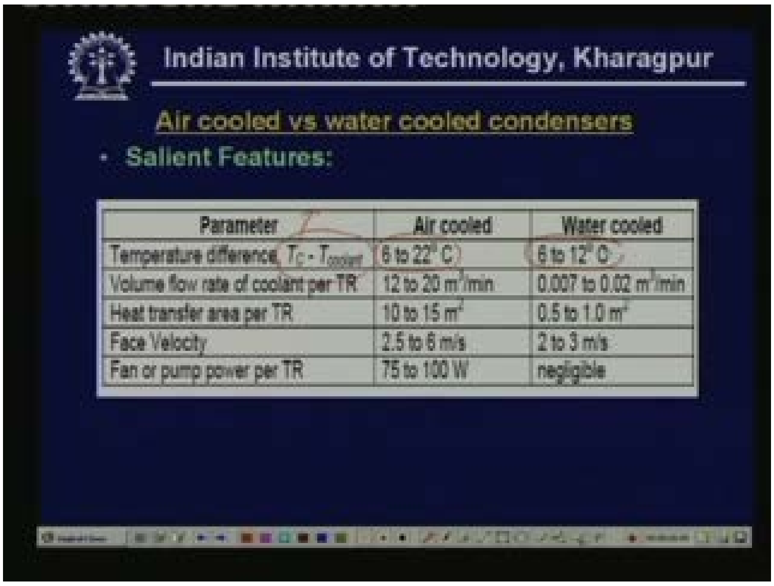

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Air cooled vs water cooled condensers

- Salient Features:

Parameter	Air cooled	Water cooled
Temperature difference, $T_C - T_{coolant}$	6 to 22° C	6 to 12° C
Volume flow rate of coolant per TR	12 to 20 m^3/min	0.007 to 0.02 m^3/min
Heat transfer area per TR	10 to 15 m^2	0.5 to 1.0 m^2
Face Velocity	2.5 to 6 m/s	2 to 3 m/s
Fan or pump power per TR	75 to 100 W	negligible

Now let us compare air cooled condenser with water cooled condenser. Let us look at the salient features here. First let us look at different parameters for example the temperature difference. Here the temperature difference is nothing but the condensate condenser temperature. That means the temperature at which condensation is taking place minus the coolant temperature okay. See you will find that in case of air cooled condensers this temperature difference varies from six to twenty-two degree centigrade. Where a, whereas in water cooled condenser this temperature difference varies between six to twelve degree centigrade. That means you can operate the condenser of a water cooled condenser based refrigeration system at a lower temperature okay. Because the required temperature different between the coolant and the condenser is small okay. In addition to that whenever we are using water as the external medium you will always find that the temperature of the water is much smaller than the drivel temperature of the air okay.

That means the external fluid temperature itself is smaller as a result you will find that compared to the air cooled condenser based system the condense, a condenser of a water cooled condenser will be operating at much lower temperature. And as you know that if you operate the condenser at a lower temperature the COP of the system will be higher okay. So in the end you find that the air cooled condenser based systems will give much lower COP compared to a water cooled condenser based system okay. Next if you look at the volume flow rate of coolant per ton of refrigeration you will find that in air cooled condensers the volume flow rate of air per ton of refrigeration varies from twelve to twenty metre cube per minute whereas it is very small.

That means about point zero zero seven to point zero two metre cube per minute in case of water cooled condenser why the volume flow rate of air is. So large because of two reasons first reason is that the density of air is almost thousand times less than that of water right the water density is if it is around thousand kg per metre cube the air density is around one point two kg per metre cube okay. So it is a order of magnetic about thousand times okay. So as a result for a given mass flow rate the volumetric flow rate will be very high if you are using air. In addition to that the specific heat of air is typically one fourth that of the specific heat of water okay.

So ultimately you will find that the rho into Cp of air is about four thousand times less than that of rho into Cp of water. As a result the required volumetric flow rate of air will be much larger than that of the volumetric flow rate of water okay. Next important performance parameter is the heat transfer area per ton of refrigeration. You will find that in case of air cooled condenser the heat transfer area per ton of refrigeration is about ten to fifteen metre square whereas it is about point five to one metre square in case of water cooled condenser. That means the required area is much larger in case of air cooled condenser compared to water cooled condenser. Again what is the reason the most important reason is that air is a bad conductor of heat compared to water as a result you find that the heat transfer coefficient that one can obtain with air is much smaller than that of water okay. Since heat transfer coefficient is small the overall heat transfer coefficient of the condenser will be small as a result the required area of the condenser will be much larger when you are using air cooled condenser okay.

Next comes the face velocity the face velocity of air cooled condenser varies from about two point five to six metre per second whereas in case of water it is slightly smaller. It varies from about two to three metre per second finally the fan or pump power per ton of refrigeration this is a parasitic power okay required for circulating the external fluid. You find that in case of air cooled condenser you require about seventy-five to hundred watts per ton of refrigeration whereas it is negligible in case of water cooled condenser. This is because the reason that the air cooled condenser the volumetric flow rate of air is much larger okay. So you have to the fan or blower has to handle much larger volumetric flow rate of the fluid as the result the required power also will be high okay.

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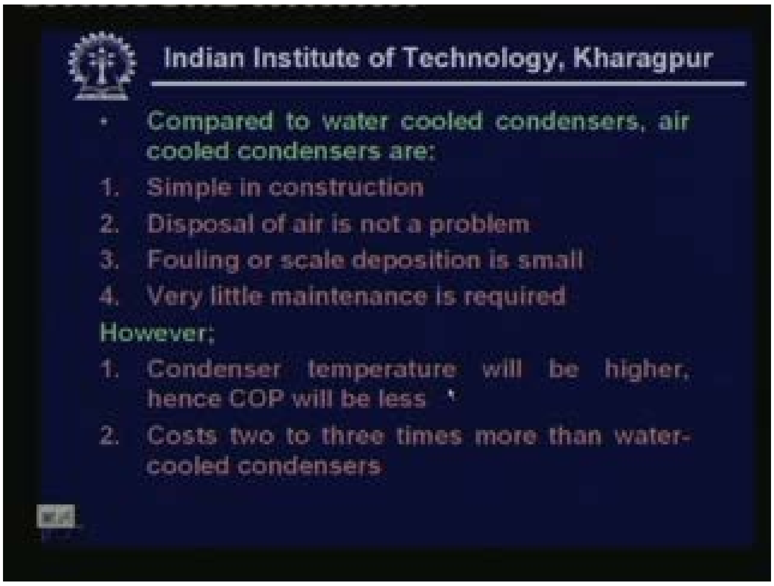

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- Compared to water cooled condensers, air cooled condensers are:

1. Simple in construction
2. Disposal of air is not a problem
3. Fouling or scale deposition is small
4. Very little maintenance is required

However;

1. Condenser temperature will be higher, hence COP will be less
2. Costs two to three times more than water-cooled condensers

Let us look at some of the advantages and disadvantages of air cooled and water cooled condensers compared to water cooled condensers air cooled condensers are simple in construction disposal of air is not a problem. And air is available in plenty and fouling or scale deposition is small compared to water cooled condensers and very little maintenance is required. So these are the main advantages of air cooled condensers. However there are certain disadvantages. As I have already discussed condenser temperature will be higher hence COP will be less and typically the cost of an air cooled condenser will be two to three times more than water cooled condensers okay. So these are the disadvantage that means initial costs will be high.

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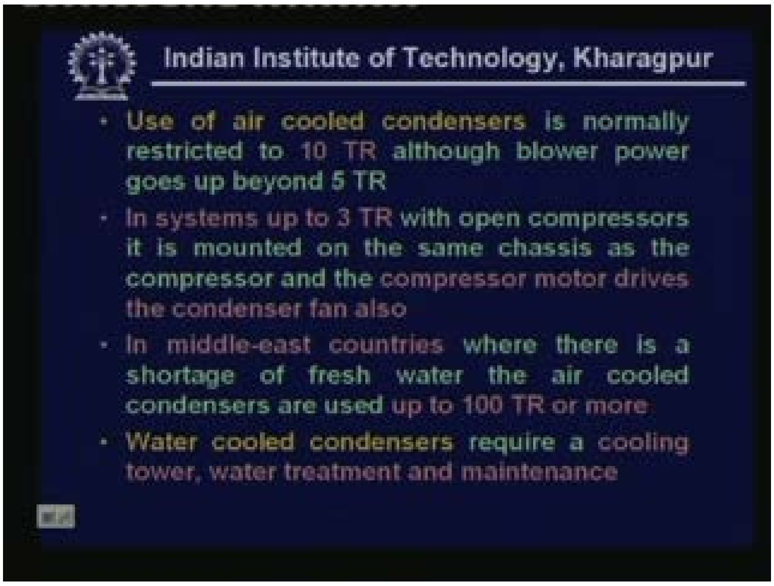

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- Use of air cooled condensers is normally restricted to 10 TR although blower power goes up beyond 5 TR
- In systems up to 3 TR with open compressors it is mounted on the same chassis as the compressor and the compressor motor drives the condenser fan also
- In middle-east countries where there is a shortage of fresh water the air cooled condensers are used up to 100 TR or more
- Water cooled condensers require a cooling tower, water treatment and maintenance

And because of these reasons use of air cooled condensers is normally restricted to ten ton capacity although the blower power goes up beyond five ton capacity and in systems up to three ton capacity with open compressors. The compressors are mounted on the same chassis as the compressor and the compressor drives the condenser fan also. As I said the whole unit is available as the condensing unit it is available of the shelf. And in middle-east countries where there is a shortage of fresh water the air cooled condensers are used up to much higher capacity. That means up to hundred tons of hundred tons of refrigeration or even more and water cooled condensers require a cooling tower water treatment and maintenance. So that is the reason why the initial cost of water cooled condenser based system is much higher than that of air cooled condenser based system okay.

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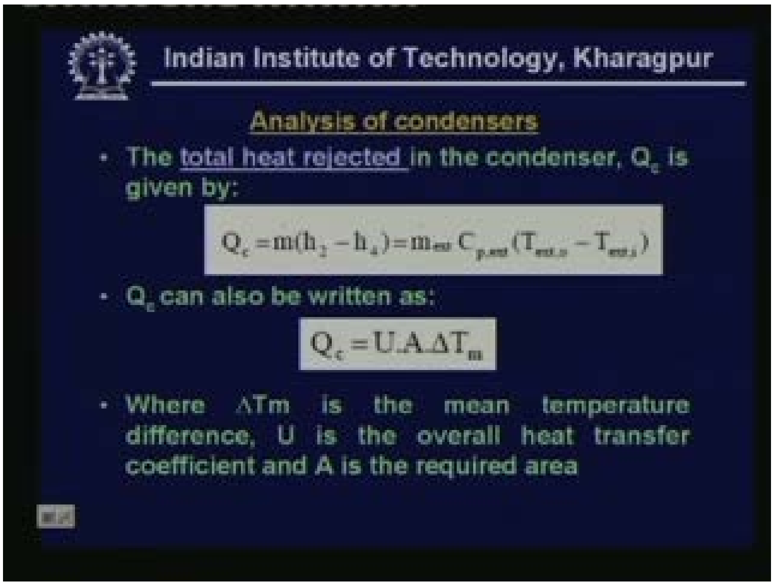

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Analysis of condensers

- The total heat rejected in the condenser, Q_c is given by:

$$Q_c = m(h_2 - h_4) = m_{ext} C_{p,ext}(T_{ext,o} - T_{ext,i})$$

- Q_c can also be written as:

$$Q_c = U.A.\Delta T_m$$

- Where ΔT_m is the mean temperature difference, U is the overall heat transfer coefficient and A is the required area

Now let us look at the analysis of condensers typically the total heat rejected in the condenser is given by Qc is equal to m dot into h two minus h four which is equal to m dot in m dot subscript external Cp external into T external o minus T external i okay. Let me show the cycle.

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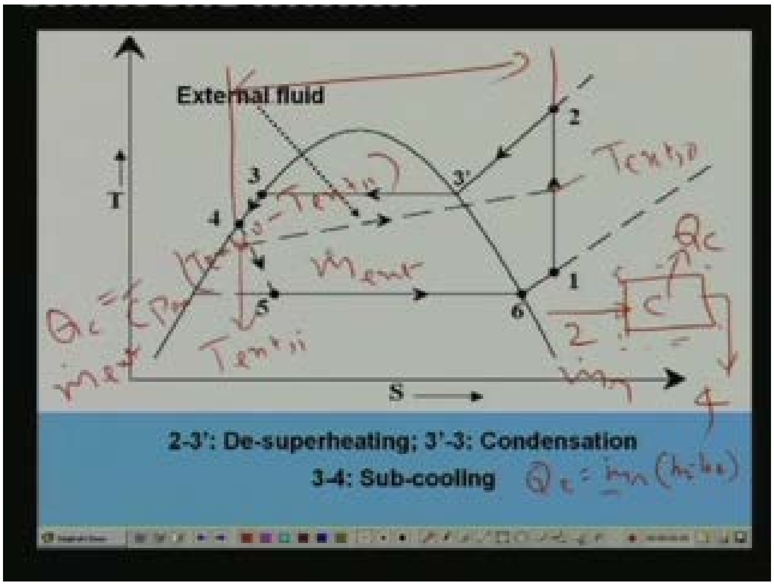

2-3': De-superheating; 3'-3: Condensation

3-4: Sub-cooling $Q_c = \dot{m}_r (h_2 - h_4)$

So it will be easy to understand. As I mentioned the heat rejection process in the condenser is from point two to four okay. So if you take the condenser the refrigerant enters at state two okay and it leaves at state four okay. So this is the condenser and it heat rejection is rejection rate is let us say Qc. And if the refrigerant flow rate is m dot r then if you take a control volume across the condenser. And if you apply energy balance and if you assume that kinetic and potential energy is changes or negligible then you can easily show that Qc is nothing m dot r into h two minus h four okay. And from the external fluid side let us say that this temperature okay. Of the external fluid is T external in and this temperature. Let us say that this is T external out and let the flow rate of the external fluid be m dot external then Qc is also equal to okay.

Let me write here Qc is also equal to m dot external into Cp some average Cp of the external fluid into T external out minus T external in okay. So this is what is shown in this equation right and now Qc can also be written as Qc is equal to U into A into delta T subscript m where delta T subscript m is the mean temperature difference U is the overall heat transfer coefficient and A is the required area.

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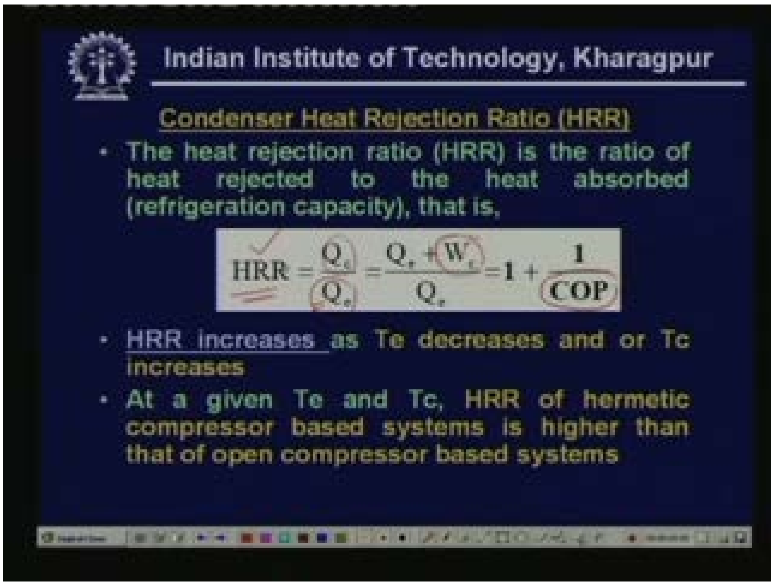

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Condenser Heat Rejection Ratio (HRR)

- The heat rejection ratio (HRR) is the ratio of heat rejected to the heat absorbed (refrigeration capacity), that is,

$$HRR = \frac{Q_c}{Q_e} = \frac{Q_e + W_c}{Q_e} = 1 + \frac{1}{COP}$$

- HRR increases as Te decreases and or Tc increases
- At a given Te and Tc, HRR of hermetic compressor based systems is higher than that of open compressor based systems

Now first let us look at what is known as condenser heat rejection ratio what is condenser heat rejection ratio the heat rejection ratio or HRR is a ratio of heat rejected to the heat absorbed okay. That means heat rejection rate in the condenser to the heat extraction rate in the evaporator and you know that heat extraction rate in the evaporator is nothing but the refrigeration capacity. So the heat rejection rate can be written as heat rejection rate is equal to Qc heat rejection rate in the rate at which heat is rejected in the condenser divided by the refrigeration capacity Qe.

Now from the overall energy balance of the refrigeration cycle we can write Qc as Qe plus Wc where Wc is nothing but the power input to the compressor okay. So finally heat rejection rate Qe plus Wc by Qe this is equal to one plus one by COP. Because this is nothing but one plus Wc by Qe and Wc by Qe is nothing but one by COP. So finally you find that the heat rejection rate is the function of COP of the system okay. So if you know the COP you can find out heat rejection rate. And if you know he heat rejection rate and refrigerant capacity of the system then you can find out what is the rate at which heat is being rejected from the condenser that is Qc okay.

Now since heat rejection rate is a function of COP it can easily be inferred that the heat rejection rate increases as evaporated temperature decreases and or condenser temperature increases okay. So let me show a typical performance curve.

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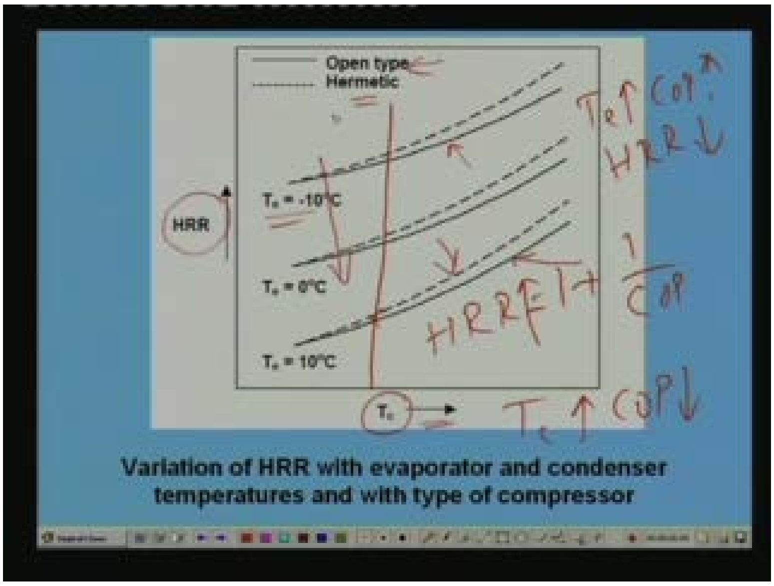

Variation of HRR with evaporator and condenser temperatures and with type of compressor

Okay, so this is the typical performance curve of a condensing unit you can see here the heat rejection rate on the y-axis and the condenser temperature on the x-axis for different evaporator temperatures for a given evaporator temperature. As you can see that as the condenser temperature increases the heat rejection rate heat rejection ratio increases. Because we know that heat rejection ratio is equal to one plus one by COP. So as Tc increases COP reduces therefore heat rejection heat rejection ratio increases as shown here. Similarly at a given condenser temperature as the evaporator temperature increases COP as that as Te increases. You know that COP increases as the result heat rejection ratio decreases that are what is shown here.

And compared to an open type of compressor you can see that for a same condenser and evaporator temperatures the heat rejection ratio of hermetic compressor is larger than that of a an open type of compressor okay. Here the solid line is for open type compressor and the dash line is for hermetic compressor. This is because of the reason that you know that in a hermetic type of compressor heat rejection also takes place from the motor as well as the compressor okay. So as a result the total amount of heat to be rejected in the condenser will be higher than that of a, an open type of condenser okay. This is also the reason why the hermetic type of compressors based systems give you lower COP okay.

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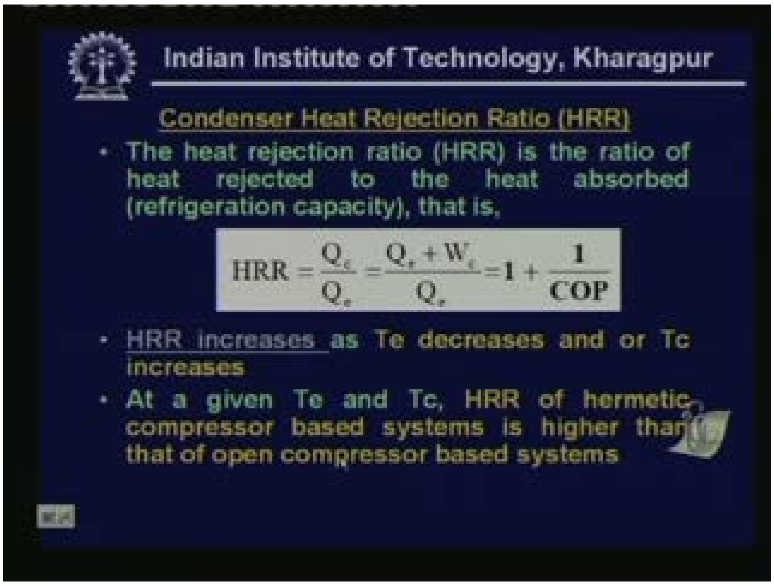

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Condenser Heat Rejection Ratio (HRR)

- The heat rejection ratio (HRR) is the ratio of heat rejected to the heat absorbed (refrigeration capacity), that is,

$$\mathrm{HRR} = \frac{Q_c}{Q_e} = \frac{Q_e + W_c}{Q_e} = 1 + \frac{1}{\mathrm{COP}}$$

- HRR increases as Te decreases and or Tc increases
- At a given Te and Tc, HRR of hermetic compressor based systems is higher than that of open compressor based systems

So that is what is mentioned here at a given Te and Tc the heat rejection ratio of hermetic based systems is higher than that of open compressor based systems.

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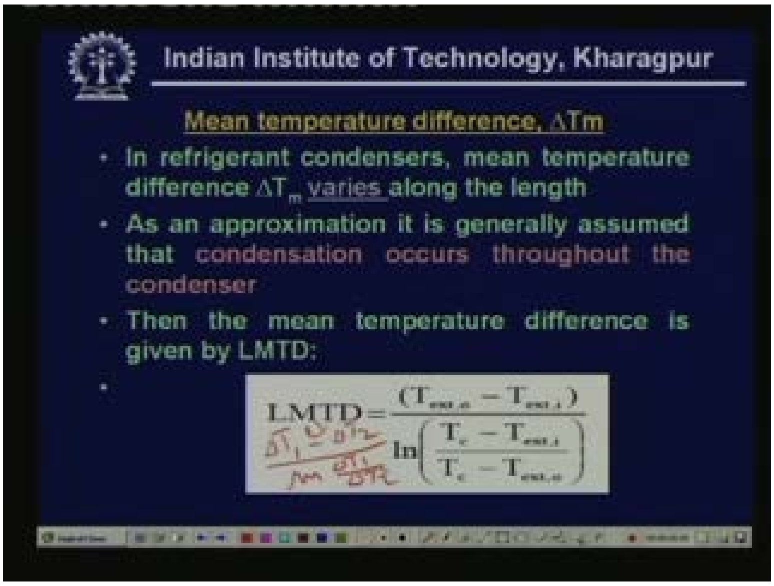

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Mean temperature difference, ΔTm

- In refrigerant condensers, mean temperature difference ΔT_m varies along the length
- As an approximation it is generally assumed that condensation occurs throughout the condenser
- Then the mean temperature difference is given by LMTD:
-

$$\mathrm{LMTD} = \frac{(T_{ext,o} - T_{ext,i})}{\ln\left(\frac{T_c - T_{ext,i}}{T_c - T_{ext,o}}\right)}$$

$$\frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$

Now let us define what is known as mean temperature difference delta Tm in refrigerant condensers. The mean temperature difference delta Tm varies along the length okay. So let me explain this.

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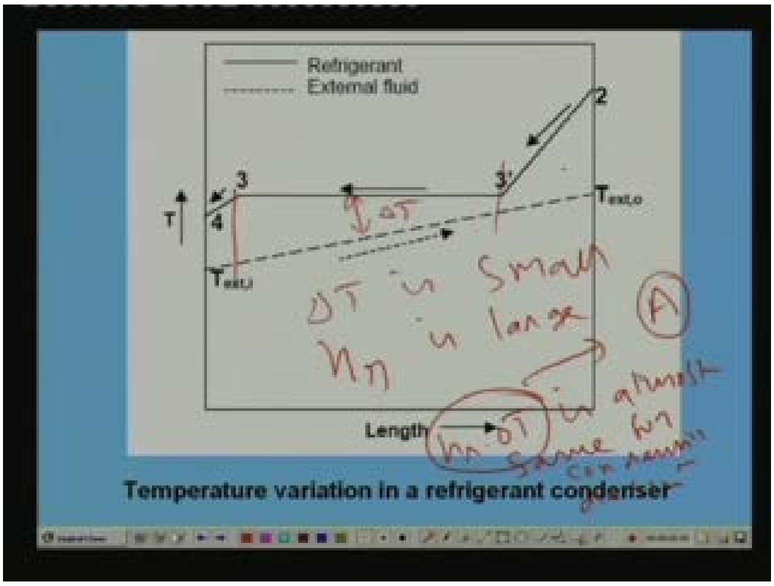

Temperature variation in a refrigerant condenser

This shows the temperature profile versus length of a typical refrigerant condenser okay. We have the refrigerant condenser here. So this is the solid line this line is for the refrigerant temperature profile whereas the dash line is for the external fluid okay. So you can see here that the refrigerant temperature varies in the initially okay. So this as you know is nothing but your de-superheating de-super heating zone okay. During this zone the pressure remains constant. But the temperature varies okay. Then you have the second stage or second zone the condensing zone okay.

During the condensing zone the temperature remains constant as long as the pressure remains constant right. Then finally you may have a third zone which is known as your sub cooling zone okay. Again during the sub-cooling zone the pressure remains constant and the temperature varies okay. So this is the temperature profile as for as the refrigerant is concerned. Now the temperature of the external fluid varies in this direction of course you get a linear variation if the specific heat of the external fluid does not vary much. So you can almost a linear temperature profile. And what I have shown here is a counter flow. That means external fluid is flowing in this direction and refrigerant is flowing in the opposite direction okay.

So the external fluid temperature as you know increases continuously as it flows through the condenser right. Now you can see that the temperature difference between the refrigerant and external fluid varies continuously okay. The temperature difference is nothing but at any point the temperature difference delta T is nothing but T refrigerant minus T external fluid right. So T refrigerant minus T external fluid varies continuously throughout the length of the condenser okay. So if you want to define some kind of a mean temperature difference it is a bit difficult here because of the continuous variation. So what is done in normal for a rough estimation of the condenser area is that we neglect the de-superheating and sub-cooling zones. And we assume that the temperature of the refrigerant remains constant throughout the condenser. And it stays at the condensing temperature corresponding to the condenser pressure.

That means the temperature inside the condenser is assumed to be at a value equal to the saturation temperature at the condensing pressure okay. That means what we do here is we assume that the temperature remains constant at the condenser temperature value okay. That means we neglect the temperature variation in the de-superheating region as well as in the sub-cooling region. So as a result you find that the under these assumptions the temperature profile will be something like that the refrigerant temperature remains constant okay. And it varies like this and the external fluid temperature varies like this okay. So the advantage of making these kind of simplification is that you can define what is known as a log mean temperature difference for the condenser if you make this type of a, an assumption. Now how this type of assumption can be justified okay. Now let us look at what happens during the de-superheating zone during the de-superheating zone you can see that the temperature difference between the external fluid.

And the refrigerant it typically large okay. That means for the de-superheating zone de-superheating zone you find that delta T which is nothing but Tr minus T external is large okay. Whereas the heat transfer coefficient on the refrigerant side that means hr is nothing but heat transfer coefficient on the refrigerant side is small okay. Why heat transfer coefficient on the refrigerant is small, because during the de-superheating process the refrigerant does not undergo any phase change okay. That means it is a sensible heat transfer process okay. So that means it is a single phase heat transfer process and heat transfer coefficient is because of the convective heat transfer coefficient due to the vapour flow okay. And vapour has lower thermal conductivity.

So you find that typically the heat transfer coefficient in this region that means in the de-superheating region is small compared to the condensing zone. Because in the condensing zone the heat transfer is both by sensible as well as latent means you find that the condensation heat transfer coefficient is much larger than that of the single phase heat transfer coefficient okay. So in the de-superheating zone hr is small whereas delta T is large okay. And if you look at the condensing zone okay in the condensing zone you find that that means this zone in this zone the temperature difference is typically small compared to this zone that means delta T is small okay. Whereas the refrigeration heat transfer coefficient during condensation is large right. So to summarise during the de-superheating phase delta T is large and hr is small and during condensation process delta T is small and hr is large. So finally we assume that or if you calculate you will find that the product hr into delta T okay, is almost same okay. For condensing as well as de-superheating zones okay. Condensing and de-superheating zones since hr into delta T is almost same the area required will also be per vat of heat transfer the area required will also be same.

So we justify saying that the, we can take a same temperature. That means we can neglect the de-super heating phase. And we can also assume during this phase also the temperature remains constant and the heat transfer coefficient during the de-superheating region is equal to the condensation heat transfer coefficient okay. This is the simplification okay. And normally the heat transfer in the sub-cooling zone is typically small. So you can neglect that for rough estimation right. So during design all that we have to do is to find out the condensing heat transfer coefficient hr and assume the temperature to remain constant at the condensing temperature okay, Tc right.

So by this means you can eliminate the temperature variation during the de-super heating and sub-cooling regions and you can have a constant temperature throughout the condenser length okay. So this procedure is very simple and it gives a rough estimation of the required area of the condenser okay. But normally in commercial condenser designs and all this is the process is not used and in those actual condenser design what is done is these three regions are I am sorry, these three regions are considered separately okay. That means the entire heat rejection process is divided into three separate regions right. And these three for these three separate regions the required areas are calculated separately. That means for this region you find out what is the mean temperature difference and what is the heat transfer coefficient and finally find out what is the area required okay for region one. Similarly for the condensation zone you find out what is the mean temperature difference and find out what is the condensation heat transfer coefficient on the refrigerant side and again find out what is the area required for the condensation region.

And similarly for the sub cooling region you find out what is the delta T mean and you find out the heat transfer coefficient single phase heat transfer coefficient and again find out what is the heat transfer area required for sub cooling. And the total area A total is nothing but A one plus A two plus A three okay. So this procedure will give you the more accurate condenser area requirement but as you can see that the process is quite complicated okay right. So now based on these assumptions we can define what is known as the log mean temperature difference. And this, so given by log mean temperature difference is nothing but T external o minus T external i divided by natural log of Tc minus T external i minus divided by Tc minus T external o okay. So this can also be defined like this for example if you have under the assumption of constant temperature let us say that we are plotting length versus temperature. So the condenser temperature remains constant at Tc okay whereas the external fluid temperature varies from T external into T external out. So the log mean temperature difference okay.

LMTD is defined a, the temperature difference at the inlet let us say delta T at one end okay. Let me call it as let us say end one and end two okay. So log mean temperature difference is defined as delta T at end two minus delta T at end one divided by natural log of delta T two minus delta T one okay. Now what is delta T two delta T two is nothing but Tc minus T external o right and delta T one is nothing but the terminal temperature difference at end one this is nothing but Tc minus T external i. So if you substitute this the Tc gets cancelled here so finally you find that LMTD is nothing but T external o minus T external i divided by natural log of Tc. Of course if you write in delta T two minus delta T one this becomes T external in minus T external out divided by Tc minus T external in divided by Tc minus T external, I am sorry T T external out divided by Tc minus T external in okay. That is what is shown here.

Of course here that is a slight this thing here it is defined in terms of delta T at terminal one minus delta T at terminal two divided by ln at delta T one divided by delta T two. It does not make any difference whether you can show it as it a different between terminal one minus terminal two divided by natural log of terminal one by divided by terminal two or terminal two minus terminal one divided by natural log of terminal two divided by terminal one okay. The final value will be same right. So if you know the condenser temperature okay. That is Tc and if you know the inlet temperature of the external fluid and from the energy balance and mass flow rate of the external fluid. If you know what is the outlet temperature of the external fluid then we can calculate what is the log mean temperature difference of the condenser okay.

Once you know the log mean temperature difference of the condenser. And if you also know the heat rejection rate in the condenser and if you can evaluate the overall heat transfer coefficient then the required area of the condenser can be obtained okay. So remember that this is a simplified procedure and this process procedure is normally used for a rough evaluation of the required area of the condenser okay. In the next lecture we shall see how to evaluate the overall heat transfer coefficient of the condenser okay. And since we know the Qc from heat rejection ratio and Qe we can calculate the required area okay. So let me summarise what we have learnt in this lesson.

(Refer Slide Time: 00:52:16 min)

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Conclusions

In this lecture the following topics are discussed:

1. Classification of refrigerant condensers
2. Salient features of different types of condensers
3. Comparison between air cooled and water cooled condensers
4. Heat Rejection Ratio
5. Calculation of Log Mean Temperature Difference (LMTD) of condensers

In this lecture the following topics are discussed classification of refrigerant condensers based on external fluid based on the construction etcetera. And salient features of different types of condensers and we have also seen the comparison between air cooled and water cooled condensers and the typical advantage and disadvantage of each of these condensers. And we have also discussed evaporative condensers and then we have defined heat rejection ratio as a function of COP of the system. And then we have discussed the calculation of log mean temperature difference and typical assumptions made in calculating he log mean temperature difference of the condensers okay.

And as I already mentioned in the next lecture. We shall see the calculation of the heat transfer coefficients on the external fluid side heat transfer coefficients on the refrigerant side. And finally how to calculate the overall heat transfer coefficient of each of these condensers. And from the overall heat transfer coefficient how to calculate the required area of the condensers okay.

Thank you.