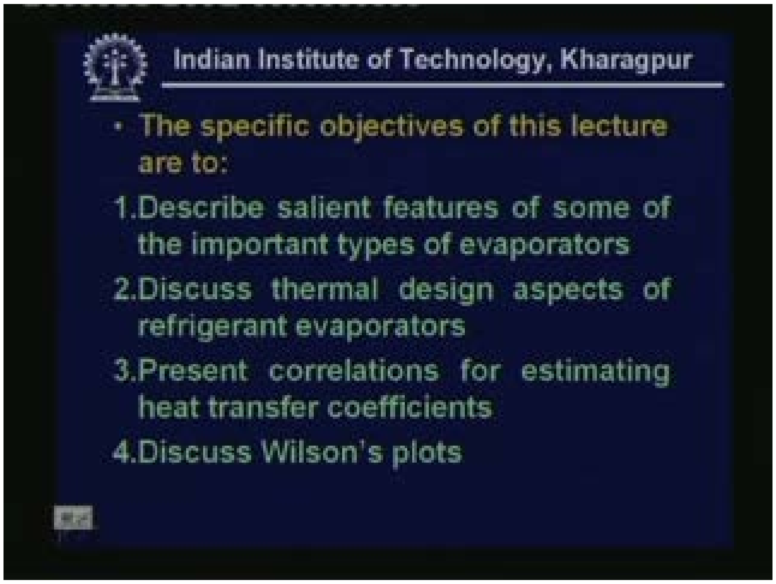
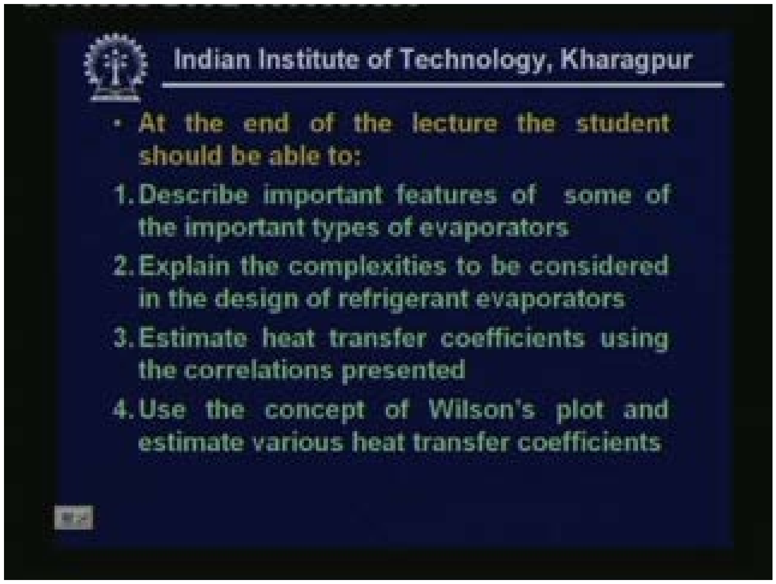
**Refrigeration and Air Conditioning**
**Prof. M. Ramgopal**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Kharagpur**
**Lecture No. # 29**
**Refrigeration Systems Component Evaporators**

Welcome back the objectives of this particular lecture are to describe salient features of some of the important types of evaporators, discuss thermal design aspects of refrigerant evaporators, present correlations for estimating heat transfer coefficients and discuss Wilson's plots.

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

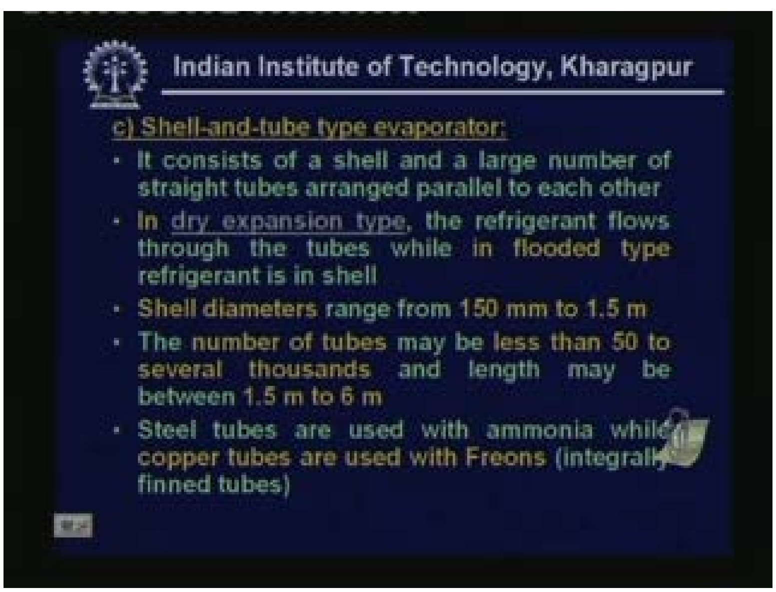


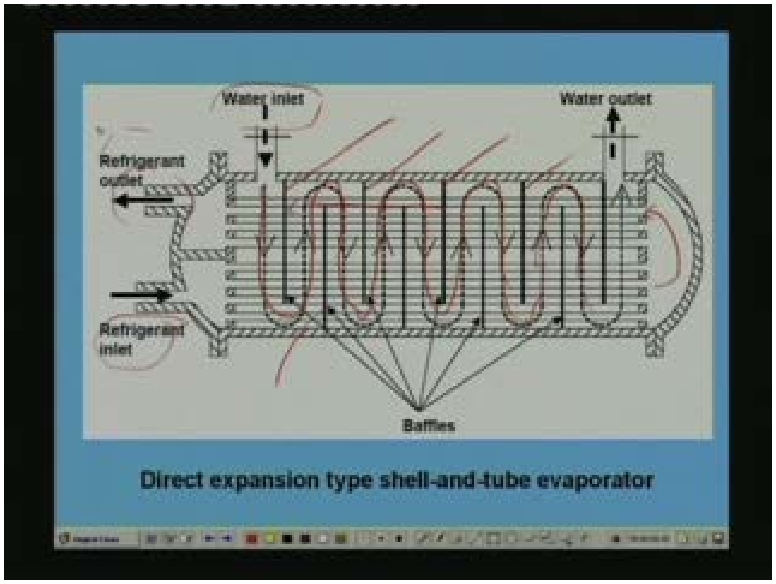
(Refer Slide Time: 00:01:06 min)




So at the end of the lecture you should be able to describe important features of some of the important types of evaporators, explain the complexities to be considered in the design of refrigerant evaporators, estimate heat transfer coefficients using the correlations presented and finally use the concept of Wilson's plot and estimate various heat transfer coefficients.

(Refer Slide Time: 00:01:28 min)






So let us look at a very important type of evaporator called as shell. And tube type evaporator the, as the name implies this kind of an evaporator consists of a shell and a large number of straight tubes arranged parallel to each other in dry expansion type the refrigerant flows through the tubes while in flooded type refrigerant flows through the shell. So let me show the picture of a dry expansion type shell and tube type evaporator. So this particular picture shows that shell and tube evaporator where the refrigerant flows through the tubes. You can see that the refrigerant flows through the tubes while the water flows through the shell okay. So this is a two pass, you can call this as a two pass as for the refrigerant is consent. Because the refrigerant flows through the tubes like this then takes the u turn. And again it is flows in this direction and finally leaves the evaporator here okay.

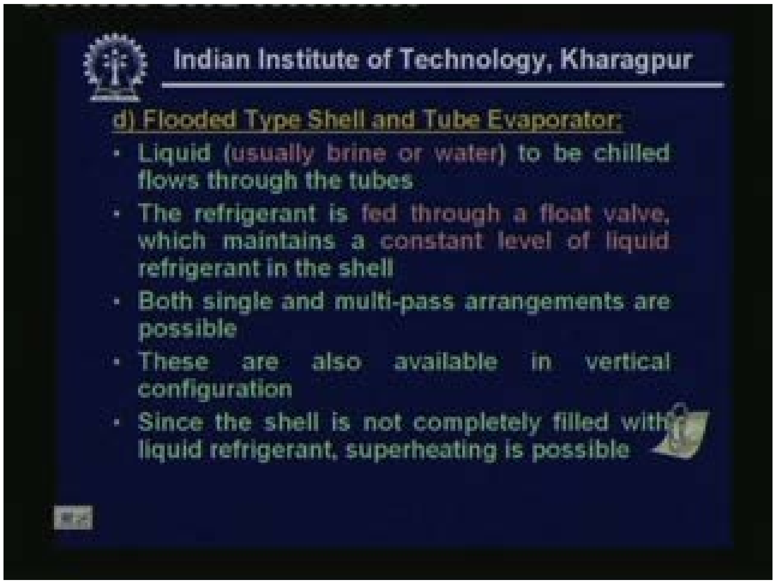
In any shell and tube type of evaporators baffles are provided. In the shell side you can see that these are the baffles okay. The purpose of the baffles is to avoid stagnant zones and also to improve turbulence. So that you can get good heat transfer coefficient on the shell side. For example you can see that because of the presence of the baffle water is force to flow like this okay. So short circuiting of the water is prevented there by you can get good heat transfer coefficient. And the stagnant regions can be avoided. Of course the baffles increase pressure drop through the shell side. So the baffle have got to be optimized. So this is the direct side expansion type shell and tube type evaporator. As I said since the refrigerant flows through the tubes at the end of the tubes you can have super heating okay. That mean water refrigerant goes out can be a super heated vapour okay.

Now let us look at the other features. The shell diameters normally range from one fifty mm to one point five meters. The number of tubes may be less than fifty to several thousands. And the length of the heat exchanger may be between one point five meter to six meters normally steel tubes are used with ammonia while copper tubes are used with Freons. And when we use Freons the heat transfer coefficient obtained on the refrigerant side is typically small. So we normally use what is known as integrally fin tubes on the refrigerant side where as in case of ammonia since the heat transfer coefficient is large fins are not required.

(Refer Slide Time: 00:03:58 min)

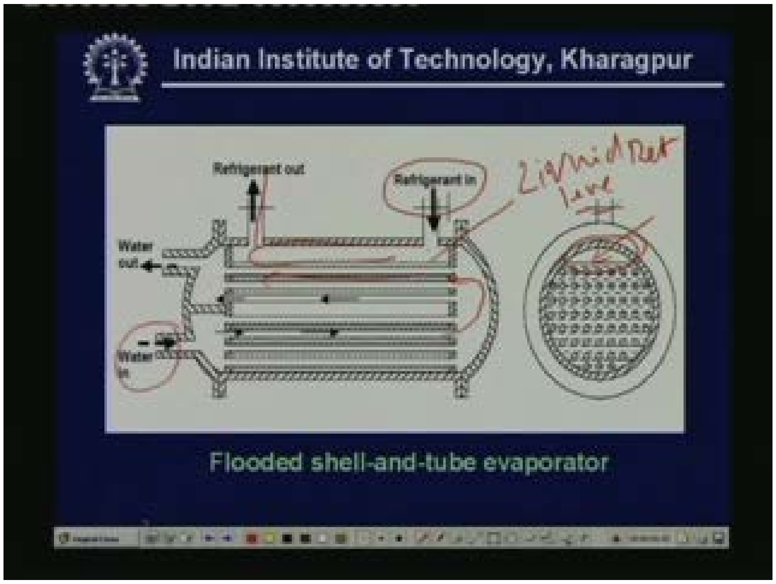

Dry expansion type evaporators uses fins inside the tube. That means on the refrigerant side while flooded type uses fins outside the tubes. Because in the flooded type refrigerant flows on the outside of the tubes dry expansion type requires less refrigerant and has positive lubricating oil return. That means the lubricating oil return to the compressor is ensured in dry expansion type and the amount of refrigerant charge required inside the system is also less. And these dry expansion type shell and tube type evaporators are normally used for small and medium capacity refrigeration plants. That means the capacity ranges from about two tons to three fifty tons whereas the flooded type evaporators are available in larger capacities ranging from ten tons to thousands of tons okay, in very large plants flooded type evaporators are used.

(Refer Slide Time: 00:04:53 min)



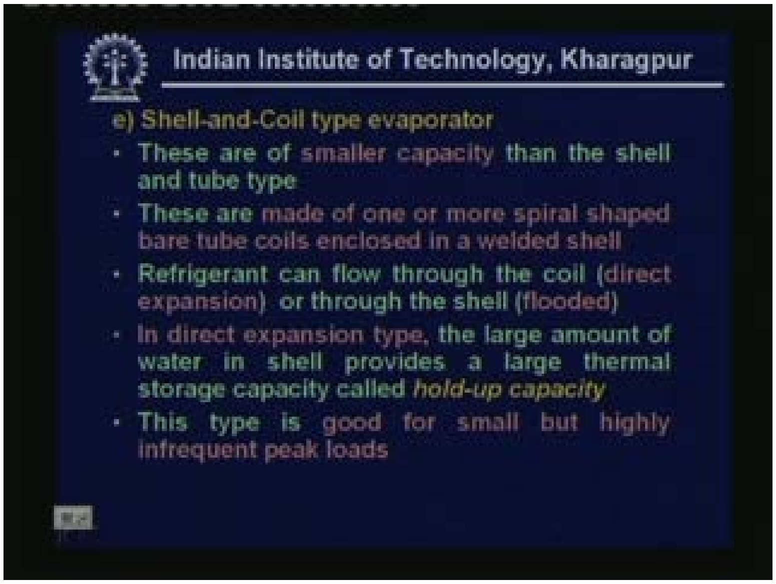

So now let us look at flooded type shell and tube evaporator as i have already mentioned the liquid. That means the external fluid which is usually either brine or water which is to be chilled flows through the tubes. And the refrigerant is fed through a float valve which maintains a constant level of liquid refrigerant in the shell. Both single and multi pass arrangements are possible and these are also available in vertical configuration. Since the shell is not completely filled with liquid refrigerant superheating is also possible.

(Refer Slide Time: 00:05:31 min)



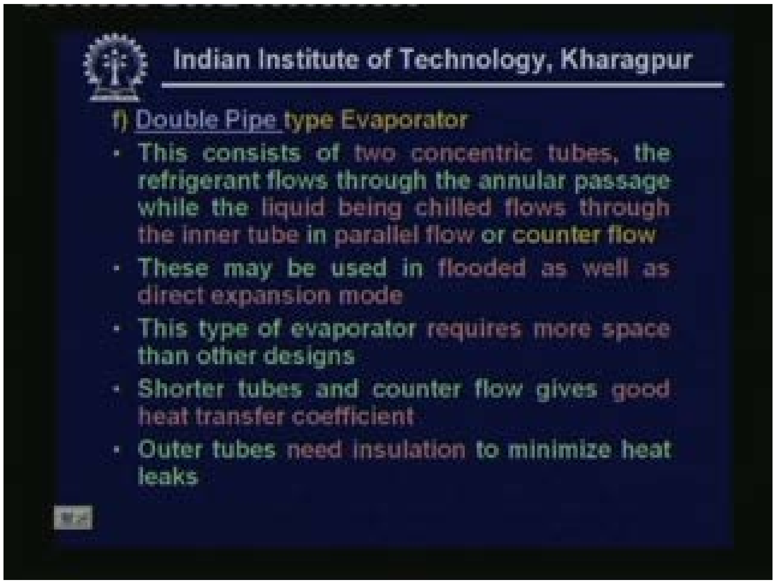
So this picture shows the flooded type shell and tube evaporator. As I have already told in this case refrigerant is on the shell side okay. Whereas the water flows through the tube side. Again this is a two pass arrangement as for as water is consent. Because water flows through the tubes like this takes a u turn and again flows back in this direction okay. So the, that means the water crosses the refrigerant path twice. So they you call this as two pass arrangement okay you can see that the, this is the liquid refrigerant level okay, liquid refrigerant level. So the, this is maintain by a float wall and the entire shell is not fill with liquid okay. You can see that there is an empty space in which refrigerant vapour is there but not the liquid okay. This is required to prevent the exit of refrigerant liquid drop let us along with the vapour okay. And since you have some space above the liquid level super heating is also possible in this kind of arrangement okay.

(Refer Slide Time: 00:06:35 min)




Now let us look at shell and coil type evaporator this is are of smaller capacity than the shell and tube type. This are made of one or more spiral shape bare tube coils enclosed in a welded shell. So this is almost similar to shell and coil type condenser which was discussed in an earlier lecture. In shell and coil type evaporator refrigerant can flow through the coil in direct expansion type or through the shell in flooded type. In direct expansion type the large amount of water in shell provides what is known as a hold up capacity. That means a large thermal storage capacity is provided by the amount of water in the shell. And this case is known as hold up capacity and this type is good for small but highly infrequent peak loads.

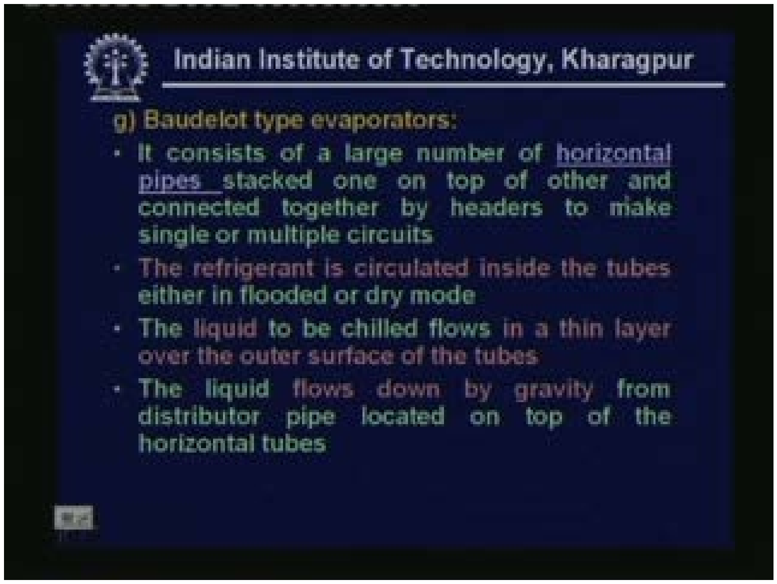
(Refer Slide Time: 00:07:28 min)




Now let us look at double pipe type evaporator. As the name implies this is almost similar to in construction to the double pipe type condenser. The, again this consist of two concentric tubes the refrigerant flows through the annular passage while the liquid being chilled flows through the inner tube in parallel flow or counter flow. These may be used in flooded as well as direct expansion mode this type of evaporator requires more space than other designs, shorter tubes and counter flow gives good heat transfer coefficient. And outer tubes need insulation to minimize heat leaks. Insulation is required because refrigerant flows through the angular space okay. And refrigerant temperature is much lower than the ambient temperature. So to reduce heat leaks you have to insulate the outer tubes. As far as the space occupied is concerned the shell and tube type evaporators occupy much less space compare to other types of evaporators and the volume is also quite small okay.

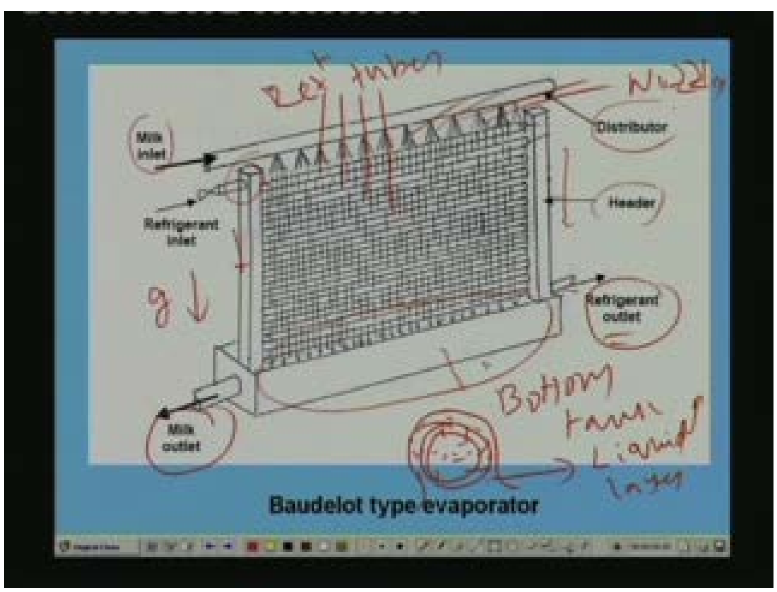
That is the reason why the shell and tube types of evaporators are very commonly used in large capacity systems okay. Whereas the tube in tube types systems which occupy more space are generally used in smaller capacity systems okay.

(Refer Slide Time: 00:08:45 min)




Now let us look at the next type this is what is known as Baudelot type evaporators this kind of an evaporator consists of a large number of horizontal pipes stacked one on the top of other and connected together by headers to make single or multiple circuits. The refrigerant is circulated inside the tubes either in flooded or dry mode. That means you can have flooded evaporator or dry expansion type evaporator. The liquid to be chilled flows in a thin layer over the outer surface of the tubes the liquid flows down by gravity from distributor pipe located on top of the horizontal tubes. Now let me show the picture of Baudelot type of evaporator.

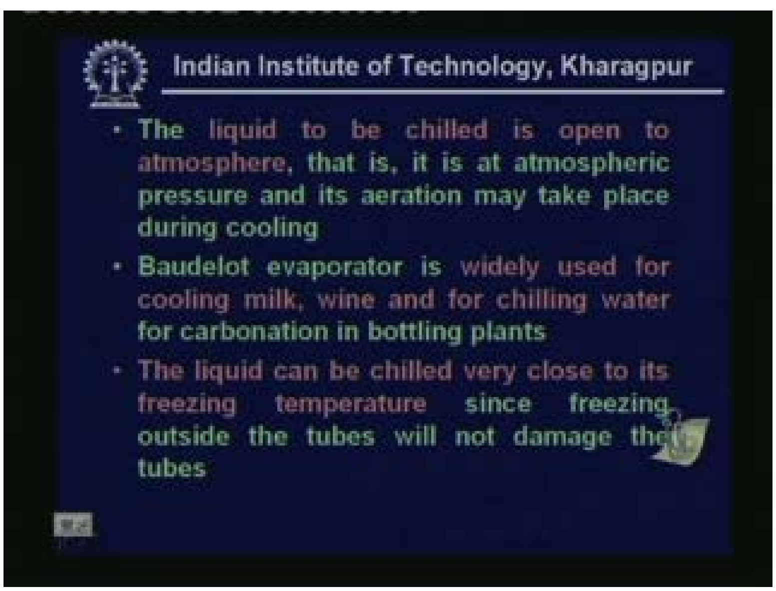
(Refer Slide Time: 00:09:29 min)



So this is the header okay. This is one header on this side and this is another header on the refrigerant inlet and inlet side okay. This is the header on the outlet side. So to this header a large number of refrigerant tubes are connected these are the refrigerant tubes okay, refrigerant tubes through which the refrigerant flows. So the refrigerant enters into the header and from the header it enters into the parallel several parallel tubes okay. And it extracts heat from the cool liquid being chilled and it exits from this header okay. So from this header it goes to the compressor now the liquid being chilled. For example milk, it enters into the header which is kept at the top okay.

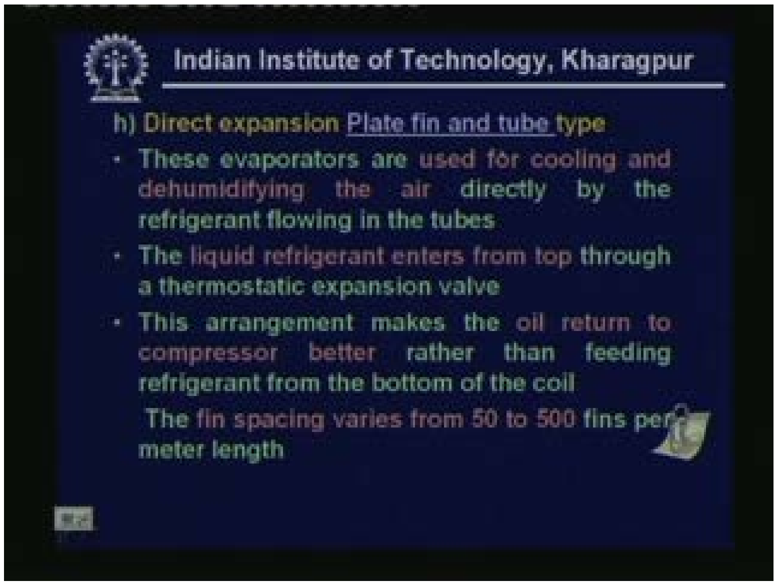
You can call this as header or distributer this has several nozzles okay. You can see that these are all the nozzles okay. Through these nozzles the liquid that is being chilled falls on to this refrigerant tubes okay, because of gravity. So gravity is in this direction. So liquid falls on the tubes and it trickles down right. And finally it gets collected in the bottom tank right the chilled milk or chilled water gets collected in this bottom tank okay. From the bottom tank it is taken out right. So if we look at a single tube we, I will find that you have a single tube like this okay. This is the wall of the tube through this tube refrigerant is flowing and outside you a thin layer of a liquid gets collected okay. So outside you have a liquid layer okay. This liquid is, the liquid that is being chilled. So the since this has a small thickness the heat transfer will be quite effective here okay. So this is known as Baudelot evaporator.

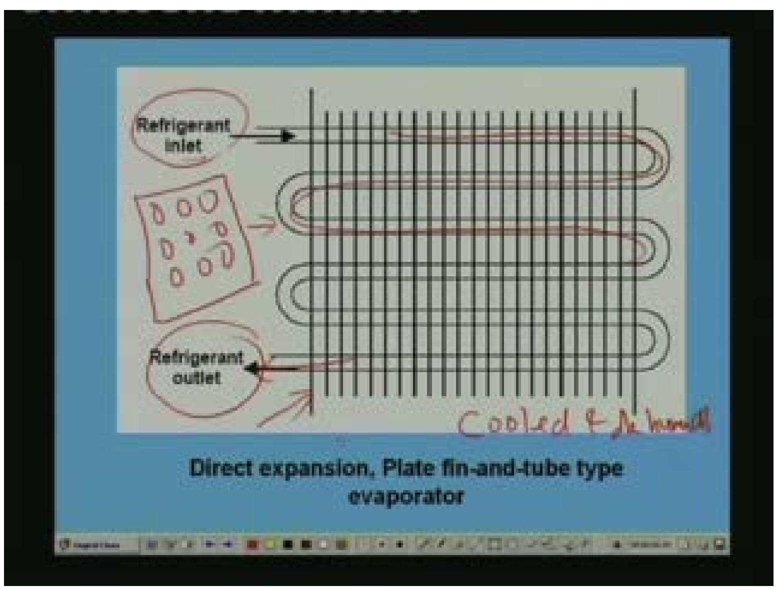
(Refer Slide Time: 00:11:39 min)



So the you can see that the liquid to be chilled is open to atmosphere. That means it is at atmospheric pressure and its aeration may take place during cooling Baudelot evaporator is widely used for cooling milk. For cooling wine and for chilling water for carbonation in bottling plants. One advantage of this kind of an evaporator is that the liquid can be chilled very close to its freezing temperature. Since freezing outside the tubes will not damage the tubes okay. So this is one of the advantage of Baudelot type of evaporator.

(Refer Slide Time: 00:12:16 min)




Next, let us look at the direct expansion plate fin and tube type evaporator. This as the name implies a plate fin and tube type evaporator is constructionally similar to plate fin and tube type condenser okay. So you here the external fluid is air right in case of condenser also the external fluid is air and the refrigerant flows through the tubes. So in case of a plate fin and tube type evaporator also the refrigerant flows through the tubes while the air flows outside the tubes okay. These evaporators are used for cooling and dehumidifying the air directly by the refrigerant flowing in the tubes. The liquid refrigerant enters from top through a thermostatic expansion valve. This arrangement makes the oil return to compressor better. Rather than feeding refrigerant from the bottom of the coil the fin spacing varies from fifty to five hundred fins per meter length.

So let me show the picture of this. So you can see that constructionally. This is almost similar to a plate fin and tube type condenser okay. So the refrigerant which flows through this tube enters at the top right. It flows like this through the tube okay, and it leaves the evaporator at the bottom. Of course you can have several rows of such tubes. That mean you can have one row behind the other and outside you have the fins and these fins remember their plate fins okay. That means if you look from the side. You have the fin and these are the tubes okay. So this is the side view if you see from this side and here the air which flows over the tubes and fins. It gets cooled as it comes in contact with the evaporator surface and depending upon the surface temperature it may also get dehumidified okay. That means both the temperature as well as the moisture content of air may reduced as the air flow through this kind of an evaporator okay. And as I said normally the fin spacing varies from fifty to five hundered fins per meter length.

(Refer Slide Time: 00:14:27 min)

In evaporators the atmospheric water vapour condenses on the fins and tubes when the metal temperature is lower than dew point temperature. Actually this is one reason why the design of evaporator that especially where air is external fluid is quite complicated. Compare to condensers because when the refrigerant temperature is low. And when the surface of the evaporator is it, at it, at a temperature lower than the corresponding dew point temperature of air then the moisture in the air will condense. That means on the evaporator surface you have both heat as well as mass transfers okay. So in the design of the evaporator you have to consider both heat transfer rate as well as mass transfer rate.

The mass transfer rate will give rise to latent heat transfer rate. That means both sensible as well as latent heat transfer rates I have got to be consider while designing the evaporators for cooling in dehumidifying applications. And as we have discussed in our earlier lectures cooling and dehumidification is mainly required in air conditioning plants. Of course in some of the cold storages also cooling and dehumidification is required okay. So this is one of the common requirements and as I said the difference between a plate fin and tube type evaporator. And condenser is that, in the condenser air does not undergo any latent heat transfer where as in the evaporator. Both sensible as well as latent heat transfer takes place on the air side also okay. And if the surface temperature, I will less than zero degree centigrade then frost also may form. That means whatever liquid condenses it, I will also freeze if the surface temperature is lower than zero degree centigrade.

This happens in domestic refrigerators and all you must have seen the evaporator of domestic refrigerator being covered with a thick layer of frost. Because the evaporator operates at a temperature must lower than zero degree centigrade in a domestic refrigerator. Hence for low temperature coils, so what is the consequence of this we have to consider this one while designing. So what is done is for low temperature coils. That means a coils which operate at low temperature such that frosting may take place a wide fin spacing. That means about eighty to two hundred fins per meter is used to avoid blockage of flow passage due to frost formation. That means you can't effort to have very close fins when there is a possibility of frosting taking place on the air side okay, if the fin spacing is very close. Then you frost forms then the frost will very soon block the air passages okay.

Once the air passages are blocked air cannot flow okay. So that, is the reason why in evaporators used for domestic refrigerators are in cold storages where frosting takes place the fins spacing has got to be wider. So as I have mentioned in earlier slide the fin spacing is normally between fifty to five hundred fins per meter as long as there is no frost formation okay. If the frost formation is there then the fin spacing varies from about eighty to two hundred fins per meter. And in the commercial evaporators you will find that the fins spacing may not be uniform okay. Especially if the fin is not plate fin tube type okay. In typically in domestic refrigerators and all the fins are provided in such a way that at the inlet where the frost formation is much faster the fin spacing is higher okay. And as the air gradually moves up the fin spacing is gradually reduced.

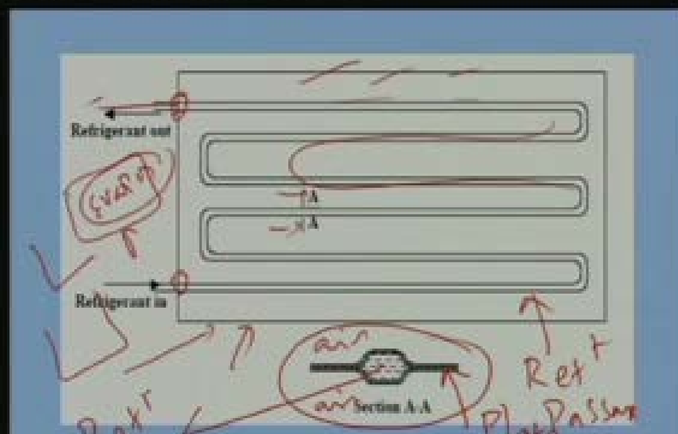
So that you can have higher heat transfer okay. So this is the very important aspect to be considered in the design of evaporators which are liked to get frosted okay. And since you cannot allow the frosting to takes place continuously frequent defrosting is required in air-conditioning applications a typical fin spacing of one point eight mm is used. That means in air conditioning applications the fin spacing can be slightly higher compare to the evaporator used in domestic refrigerator. Because in air conditioning applications water condenses but it does not form frost if it forms frost then frost cannot leave the evaporator surface okay. It sticks to the evaporator surface. Then it is, it start blocking the air flow passage whereas if water only condenses. Then do to gravity it can trickle down okay. It will not affect the air flow passage that is the reason why in air conditioning applications the fin spacing is much smaller compare to a domestic frost free evaporator okay.

(Refer Slide Time: 00:18:58 min)

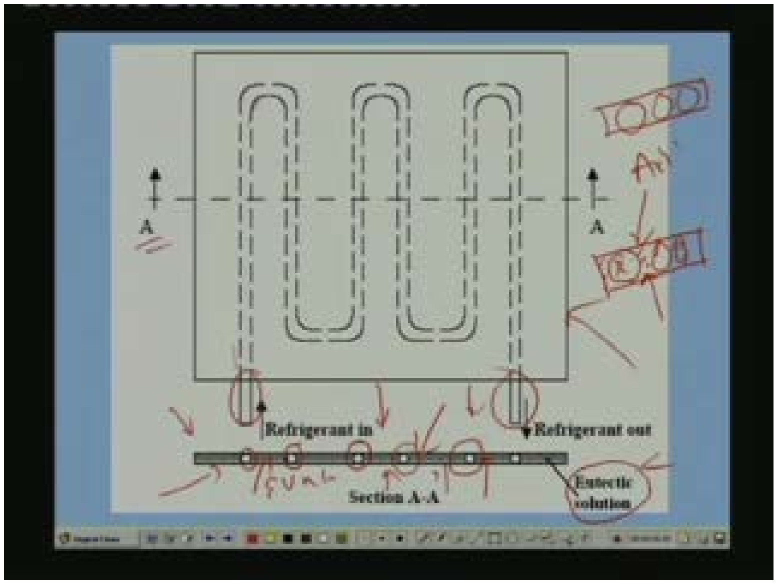
## Indian Institute of Technology, Kharagpur

i. **Plate Surface Evaporators**

- Roll-bond type evaporators are used in domestic refrigerators
- In another type, a serpentine tube is placed between two metal plates such that plates press on to the tube
- The edges of the plates are welded together
- The space between the plates is either filled with a eutectic solution or evacuated
- If eutectic solution is provided, it provides a good hold-up capacity
- Widely used in refrigerated trucks




Roll-bond type evaporator




Now let us look at plate surface evaporators plate surface one type of plate surface evaporator is also known as roll bond type evaporator and this is normally used in conventional domestic refrigerators okay. That means not automatic refrigerators but refrigerators in which frosting has to be done manually okay. So let me show the picture of roll bond type evaporator this is the roll bond type evaporator okay. So it basically consists of a plate which consists of refrigerant tubing okay. So this is refrigerant passages I should not call it a tubing. But this is refrigerant passage okay. Through which the refrigerant flows for example refrigerant enters like this flows this way okay. And finally leaves like this and air flows over the outside. That means on this surface you have air and if you take a section at, let us say at air the section looks like this okay. So this is your plate okay. And this is your refrigerant okay, and air is on the outside. So the manufacturing of this is quite interesting what is generally done is a two aluminum plates of a equal size. That means equal thickness equal width etcetera are taken.

And on this aluminum plates the refrigerant circuit is printed. That means it just like your PCB okay, printed circuit board the refrigerant tubing circuit is printed on this printing means some ink is deposited in the way the tubing is required okay. So once the printing is done both this aluminum plates are brought together and both the plates are send to rolling mills okay. So both the plates are rolled in rolling mills. So when the plates are rolled in let us say hot rolling mills then bonding of the two plates takes place that means both the plates get fused together and they form a single plate this bonding takes place everywhere except where there is ink okay. So wherever there is ink the bonding does not takes place okay. That is the characteristic of the ink used okay. So after the rolling process what is done is the refrigerant passage that means wherever ink is there is insulated by sending high pressure water or high pressure air okay. Since there is no bonding wherever there is ink at that point under high pressure the tubes. I mean the plate can get initiated okay.

That means plates remain separate only where there is ink rest of the place they get fused okay. Since they are separate where ink is their, they can be inflated by sending high pressure fluid okay. So once the high pressure fluid is send the refrigerant flow passage is found okay. So once a, the high pressure fluid is send the refrigerant flow passage is formed okay. So once the passage is formed the high pressure is switched on then it is cleaned right. So what you have is a single plate okay, which is made of two separate plates a single plate consisting of inbuilt refrigerant passages through which refrigerant can flow okay. So that is what is shown here you have the finally where an everything is over at this point the inlet and outlet tubes are welded to the roll bond type evaporator okay.

Through this tube refrigerant enters and through from this it comes out and this plate can be bent into any form. For example this plate can be made into the form of a box or it can be made into the form of a u it can be bent into the form of l lets, so it can be bent into any shape. And this is nothing but your evaporator and it also is nothing but your freezer box this is what you see in a conventional domestic refrigerator the moment you open the door you find the freezer box okay. And you will also notice that the freezer box consists of some protrusions okay. And freezer box made of aluminum plate and it have some protrusions that is nothing but your refrigerant flow passage through which the refrigerants flows okay. This kind of evaporator is very effective a and it’s also easier to manufacture and it is cost wise also it is good it is cheaper compare to the tube and plate type evaporator okay.

That is the reason why most of the manufacturers. Now a days use this kind of evaporators in domestic refrigerators okay. In addition to that because the very good bonding the heat transfer is very effective okay. And if you look at any single tube you find that this area acts as a fin okay. And the contact is in between the fin and the refrigerant is all most negligible okay, because they are formed of the same plate right. So this are the advantages of roll bond type of evaporator which are used in conventional domestic refrigerators and may other applications that is another type of plate surface evaporator in this type a serpentine tube is placed between two metal plates such that the plates press on to the tube okay.

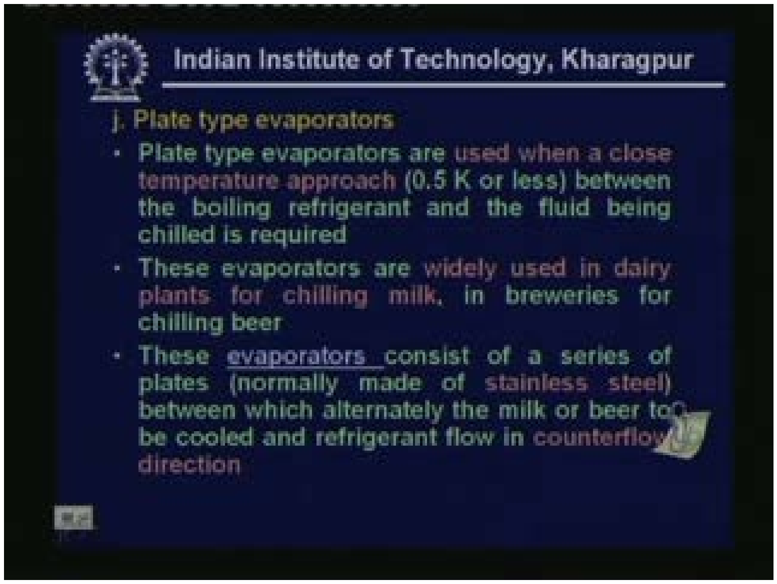
So let me just describe it first the edges of the plates are welded together the space between the plates is either filled with a eutectic solution or evacuated. If eutectic solution is provided it provides a good hold up capacity. And this kind of evaporators are widely used in refrigerate refrigerated trucks okay. So let me describe this so you can see here okay and this is the sectional view at air right. So if you this is like a closed box right a closed box in which the refrigerant tubes okay. The serpentine tube is sandwiched right. That means you take two plates and put this serpentine coil and close all the edges right and have the inlet and outlet right. Now you have some space between the refrigerant this is the refrigerant tube okay. These are the refrigerant tubes and this is the plate over which your air flows air or water is the external fluid that flows right.

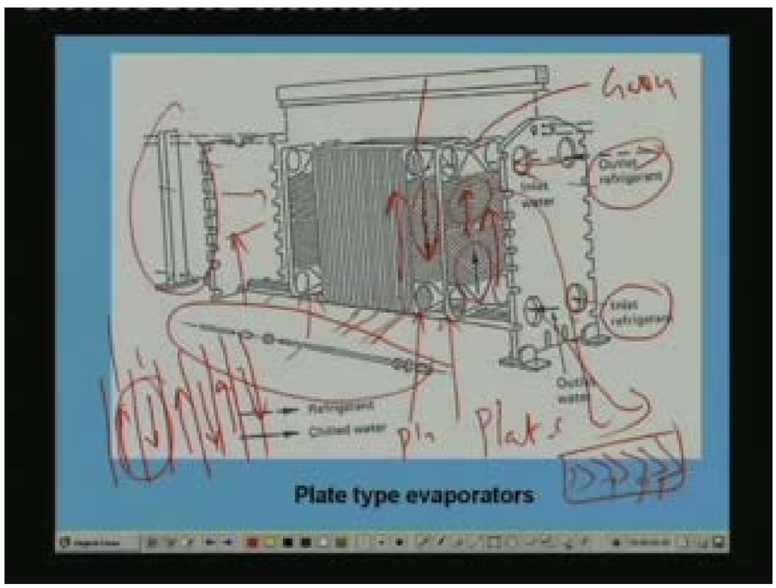
So there is a gap between the tube and the plate okay. So all this space so that space is normally filled with the eutectic solution okay. Eutectic solution means a solution which has low freezing point right. So when you fill this space with the eutectic solution. That means this space then there is a good thermal contact between the refrigerant tube and the outer plate okay. Because the eutectic solution which is a liquid has high thermal conductivity compare to air or vacuum's as the result. You get good performance okay. In another method what is done is this space is not filled with any solution but it is evacuated okay. When you evacuated the outside pressure which is atmospheric that pressures this to outer tubes. As a result again good thermal contact is formed between the tubes and the plates right. But more widely the eutectic solution is used because the advantage of eutectic solution is that in addition to providing good thermal contact it also provides what is known as hold up capacity. That means when you have lot of solution in the evaporator okay.

Lot of external fluid in the evaporator the external fluid has since it is a liquid it has large specific heat right and it also has large mass because of it is high density okay. So you have large MCP liquid which is cool to almost the same temperature or few degrees higher than the evaporator temperature okay. So that means the entire you have a pack or you have an evaporator which has high large thermal capacity and which is cool to a low temperature okay. Now let us say that there is a power cut okay. If there is power cut then refrigeration is not provided refrigerant system does not work. So no refrigeration is provided because the compressor does not work. But still because of the large hold up capacity that means because of the large amount of liquid which is originally present in the evaporator. And which was at very low temperature the refrigerated space can be main it cooled for a longer time okay. That means this liquid the eutectic solution continuously gives a cooling as long as its temperature is low okay.

So this kind of capacity is known as hold up capacity okay. So this is one of the advantage of having this eutectic solution okay. It can take care of power cuts or load variation etcetera okay and this is very widely used and refrigerated trucks what is done in a refrigerated truck is this evaporators are connected to refrigeration systems which are on the land okay. So just before the truck starts all this evaporators are cooled to the required temperature. That means the eutectic solution is cool to the required low temperature okay. Then the evaporators are disconnected from the refrigeration system and they are placed in the refrigerated truck okay. Then the truck moves from one place to the other. So as long as the truck is on the move cooling is provided by the cooled solution placed in the evaporators okay. So the that way is the simple system and evaporation is are I am sorry cooling is ensured even when the truck is moving without putting any refrigeration system on board okay. So this is one of the popular ways of providing refrigeration okay.

(Refer Slide Time: 00:28:24 min)




Now let us look at another very important type of evaporator what is known as plate type evaporator plate type evaporators are used when a close temperature approach. That means point five Kelvin or less between the boiling refrigerant and the fluid being chilled is required okay. That means let us say that refrigerant is at minus twenty degree centigrade. And I want to chill the external fluid to minus nineteen point five degrees okay. That means refrigerant temperature and the external fluid temperature are all most same okay. The difference is very small about point five Kelvin then we require very high heat transfer coefficients and all okay. And you also require basically very high heat transfer area also right. In such cases the plate type evaporators are used okay. That means wherever you want very close approach plate type evaporators are used these evaporators are widely used in dairy plants for chilling milk in breweries for chilling beer etcetera. These evaporators consist of a series of plates normally made of stainless steel between which alternately the milk or beer to be cooled and refrigerant flow in counter flow direction.

So let me show the picture of a plate type evaporator. So you can see here that there are a large number of tubes. For example this I mean large number of plates sorry, you have a, this is one plate and this is another plate okay. So like that a number of plates are staged together okay and the flow passage is their between these two plates okay. That means there is some gap between these two plates through which the fluid can flow right. For example let us say that here the refrigerant is flowing in this direction okay. So in the passage formed this plate and the next plate that means in this passage the liquid being cooled will be flowing in the opposite direction. That means one fluid flows in this direction the other fluid flows in this direction okay. So in the next passage that means the passage formed between this plate and the next plate again the refrigerant flowing will be flowing in this direction okay.

That means if you look at the plates let us say these are the number of plates which are stack together if refrigerant will be flowing like this okay. In alternate path and liquid being cool will be flowing like this okay. So this is refrigerant and this is of the external fluid. So you can see their between the passages a true counter flow can be obtained. So as we know the counter flow gives rise to very effective heat transfer okay. And you can also see that these plates are not plain plates. But they have some profile on that normally they are they have some structure in such a way that a good turbulence and a hence high heat transfers coefficients can be obtained okay. Normally hiring bone structure are something like that is used okay. So the plain plates are taken and they are stamp with the required structure.

So that you get high heat transfer coefficient okay. So you have a if it look at each plate you will have this kind of stampings and you can see that the refrigerant enters for example in this figure, through the end plate okay. It enters like this. So flows through alternate passages okay and it comes out like this okay, where as water enters through this passes again flows through the evaporator. And it comes out from this passage in the end plate okay. And the ends are closed you have one end plate this is one end plate and this is end plate and when everything is put together. We also require a gasket to prevent leaks for example this is a gasket. So each plate will have gasket on both sides and the gaskets will prevent leaks of refrigerant and also a provide the gap for flow passage okay. So when you stage the plates together and closed with the end plates then a closed evaporator is formed and the entire evaporator is assemble okay. So you have the assembly tie rods all that okay.

So finally when you assemble it you get a very compact evaporator which has very high heat transfer area okay. So high capacity right. So this is what is known as your plate type of evaporator now a days it is becoming popular especially in large systems and also in dairy plants. And all where milk is used the reason why it is becoming popular in dairy plants and all is that in dairy plants you have to clean the evaporators almost every day okay, because once the milk flows through its certain amount of time cleaning is required. So to have to maintain the hygiene right and if you are using let us say evaporator like shell and tubes of evaporator cleaning is very difficult or it may take lot of time okay. Whereas in plate type evaporator since the weight is constructed and the, since by the weight is assembled. If you want to clean it you have to remove some bolds remove the end plate then all the plates are accessible okay

So you can remove one by one plate and clean it and again stag them together and assemble the whole evaporator okay. So the removing the plates and cleaning and again assembling them back does not take much time okay. So this is very convenient in this kind of plants where hygiene is important and cleaning is required frequent cleaning is required okay. That is why this are very ideal in addition to that if you want to increase the capacity of the evaporator or reduce the capacity of the evaporator. All that you have to do is you have to remove the bolds take out one end plate and add few plates. If you want to increase the capacity or remove some plates if you want to reduce the capacity okay. So capacity re-educationer increase is possible very easily right that is the reason why these evaporators are becoming popular in addition to their being very effective okay.

(Refer Slide Time: 00:34:41 min)


And the overall heat transfer coefficient in plate type evaporator is very large you get about four thousand five hundred watt per meter squared Kelvin for ammonia water and three thousand watt per meter squared Kelvin for R twenty-two water. And these type of evaporators require very less refrigerant inventory for the same capacity okay. That means the total amount of refrigerant to be charged into the system is much less when you are using plate type evaporator. For example it will be about ten percent of shell and tube type evaporators for same capacity okay. So this is an advantage because it reduces the cost. And if it using some toxic refrigerant it is also safer to have less refrigerant and cleaning the evaporator in dairy plants and breweries is very easy. As I have already explained the capacity can be increased or decreased very easily by adding or removing plates this is also I have explained.

(Refer Slide Time: 00:35:58 min)


Okay, so this are some of the important types of evaporators in fact if you look at evaporator unlike condensers there can be many a large variety of evaporators okay. Normally condensers can be made of the shelf or you have standard types of condensers which can be a made to order or which can be obtained of the shelf. But evaporator generally are made to order okay. Most of the time the evaporators are non standard depending upon the applications except for may be a shell and tube type or a plate fin and tube type or plate type okay. The roll bond type of evaporator etcetera are made depending upon the requirement okay. The designing and manufacturing etcetera is done based on the specific requirements. So you have a wide variety of evaporators okay depending upon a wide variety of applications okay. This one again the difference between evaporator and condenser okay.

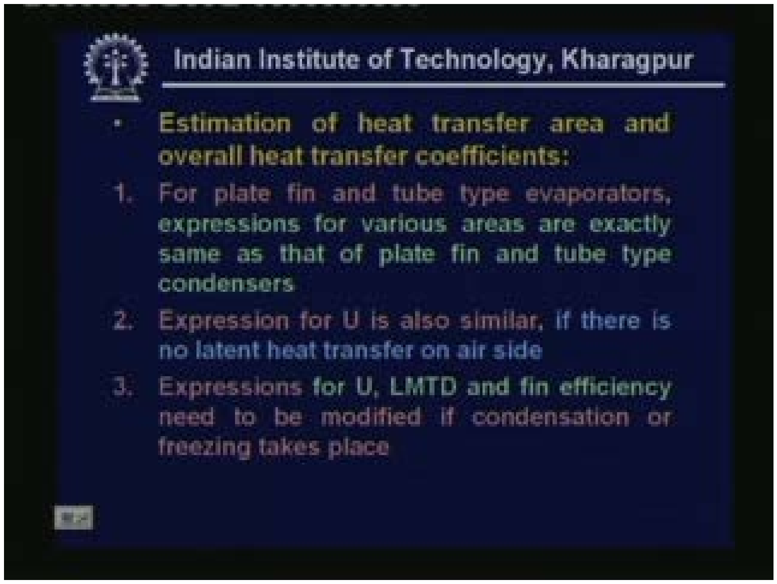
Now let us look at the thermal design of evaporators when I say thermal design of evaporators. Actually the design of evaporator is very complicated unlike the design of condenser because of the factor that we have both we can have both sensible as well as latent heat transfer taking place on the external fluid side also okay. In addition to that the prediction of refrigerant coefficient on the boiling side is also quite difficult unlike that of condensation okay. For this reason the very exact design of evaporators is quite difficult okay. So there are large number of correlations available which are applicable to particular ranges or particular flow patterns etcetera. So depending upon our the type of the evaporator that we are planning to use we have to use the suitable correlations okay.

So I will not really going to the details of the exact design of evaporators which you will normally study in a in advance course I will simply explain the basic principles and the complex cities to be considered while designing the evaporator okay. First let us look at the complexities. The design is complex due to refrigerant side heat transfer coefficient varies widely along the length both sensible and latent heat transfer may take place on external fluid side.

As I have already told presence of lubricating oil in evaporator okay. In condenser normally if it is a, if a refrigerant is missile with the oil then a, the presence of oil does not affect the heat transfer or pressure drop. But what happens is when you come to the evaporator the oil tends to get separated from the evaporating refrigerant okay. That means once a liquid starts boiling then lubricating gets separated from the refrigerant once it gets separated it tries to stick to the evaporator tube and it tries to settle down in the evaporator okay. So this will complicate the design because you have to make sure that the refrigerant lubricating oil is flowing back to the compressor okay. To ensure that the compressor is operating properly okay. So the oil return has to be considered a while designing the evaporators in addition to that the presence of large amount of oil in the evaporator will also affect the heat transfer and pressure drop characteristics of the evaporator which need to be considered okay.

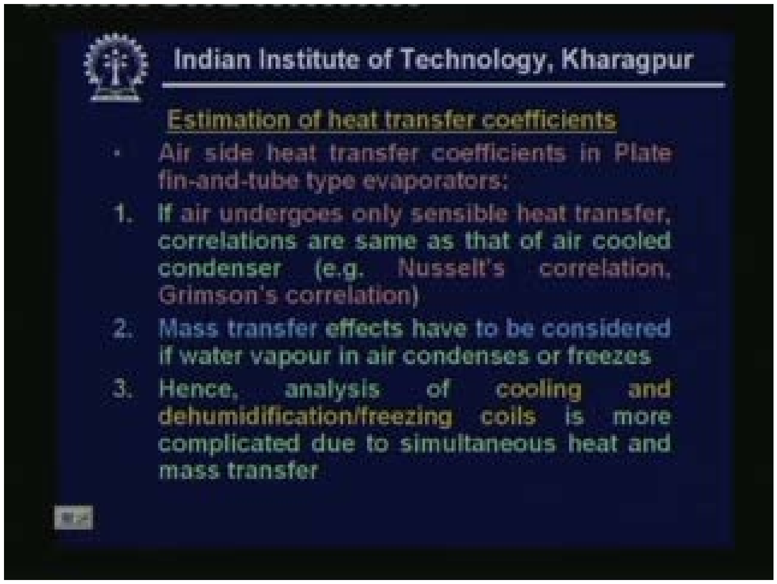
So this makes the design complicated and evaporator pressure drop is more critical. That means this I have already explained in an earlier lecture compared to the pressure drop on the condenser side. The pressure drop on the evaporator side has a more significant effect on the performance of the system okay. So you have to design the evaporator in such a way that the pressure drop is less than the acceptable level okay. That means it is as well as possible it should be as small as possible okay. This again puts constrains on the design of the evaporator. As I have already explained the refrigerant velocity has to be optimized taking both oil return and pressure drop into account. And finally the part load operation may lead to flooding of the evaporator which may lead to signify of the compressor.

(Refer Slide Time: 00:39:48 min)




Estimation of heat transfer area and overall heat transfer coefficients for plate fin and tube type evaporators expressions for various areas are exactly same as that of plate fin and tube type condensers. This we have discussed in detail while discussing the design of condensers. So the how to calculate area that is exactly same okay. Expressions for overall heat transfer coefficient is also similar as long as there is no latent heat transfer on air side okay. If there is no latent heat transfer on air side and if only sensible heat transfer takes place on the air side then the design. That means the expressions for U expressions for various area expressions for fin efficiency etcetera. Their exactly similar for plate fin and tube type of evaporator as that of plate fin and type tube of condenser which we have already discussed right. Expressions for U LMTD and fin efficiency need to be modified if condensation or freezing takes place okay. On the other hand if you have latent heat transfer on the external fluid side also then you have to consider these aspects also.

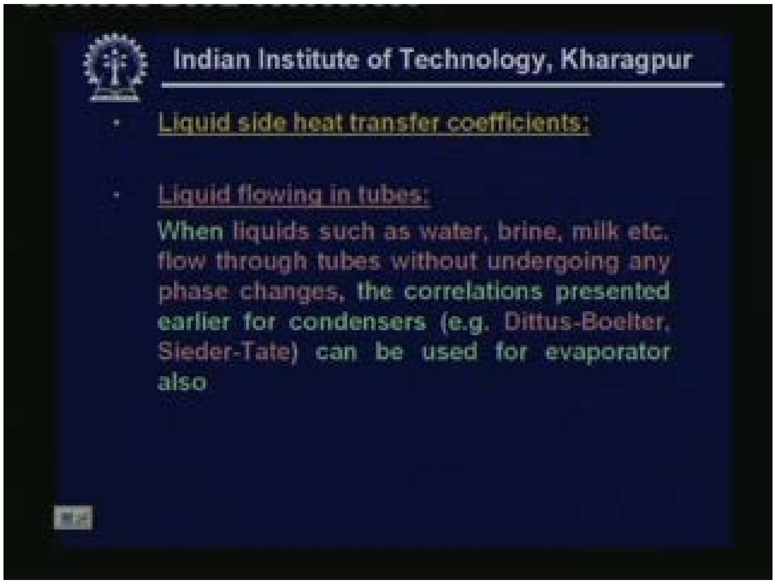
(Refer Slide Time: 00:40:53 min)




Now let us look at estimation of heat transfer coefficients air side heat transfer coefficients in plate fin and tube type evaporators. As I said these evaporators are normally used in large in small air conditioning systems or in cold storages if air undergoes only sensible heat transfer correlations are same as that of air cooled condenser okay. That means air side that is only sensible heat transfer.

Then you can use the same correlation that we have use for condensers namely. For example Nusselt's correlation Grimson's correlation etcetera. Mass transfer effects have to be considered if water vapor in air condenses or freezes hence analysis of cooling and dehumidification or cooling and freezing coils is more complicated due to simultaneous heat and mass transfer okay. So to design cooling and dehumidification or cooling and freezing coils one has to know the mass transfer aspects also. Because you have to consider the simultaneous heat and mass transfer on the air side okay. This is quite complex and normally this is a studied in advanced refrigeration courses okay.

(Refer Slide Time: 00:42:03 min)

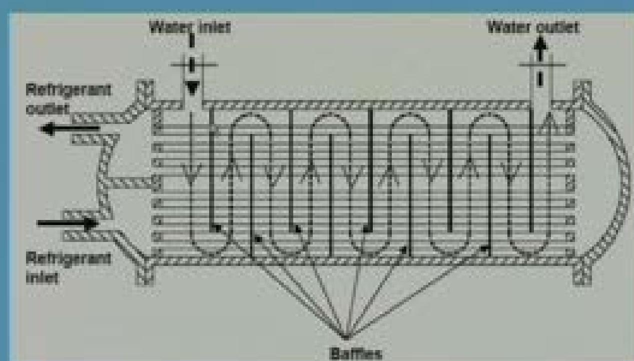



Now let us look at liquid side heat transfer coefficients liquid flowing in tubes when liquid such as water brine milk etcetera flow through tubes without undergoing any phase changes. That means as long as it does not freeze it should not freeze. But as long as it does not undergo any phase change the correlations presented earlier for condensers. That means correlations such as Dittus Boelter or Sieder-Tate can also be used for evaporator okay. The exactly same correlations can be used with a small change in the Dittus Boelter correlation. For example the you have prontle number. And the exponent of prontle number is point four because their the liquid is being heated as it flows through the condenser right. But when you use the same expression for evaporators, for the external fluid then instead of using point four for prontle number you have to take point three in Dittus Boelter correlation. Because the liquid is being cooled in case of evaporator this is the only change otherwise the correlation will be exactly same okay.

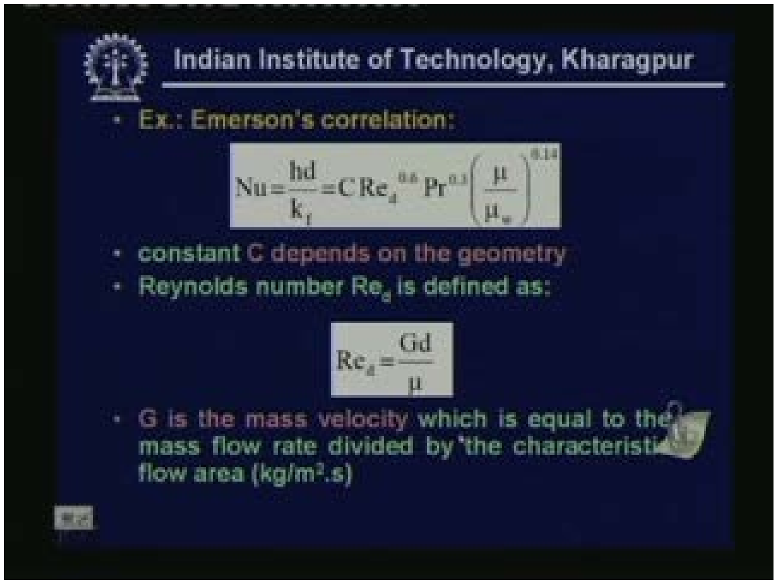
(Refer Slide Time: 00:43:05 min)

Indian Institute of Technology, Kharagpur

- Liquid flowing in a shell:
- In direct expansion type, shell-and-tube evaporators refrigerant flows through the tubes, while water or other liquids flow through the shell
- Analysis of fluid flow and heat transfer on shell side is very complex due to the presence of large number of tubes, baffles etc
- Several empirical correlations based on experimental observations have been developed over the years



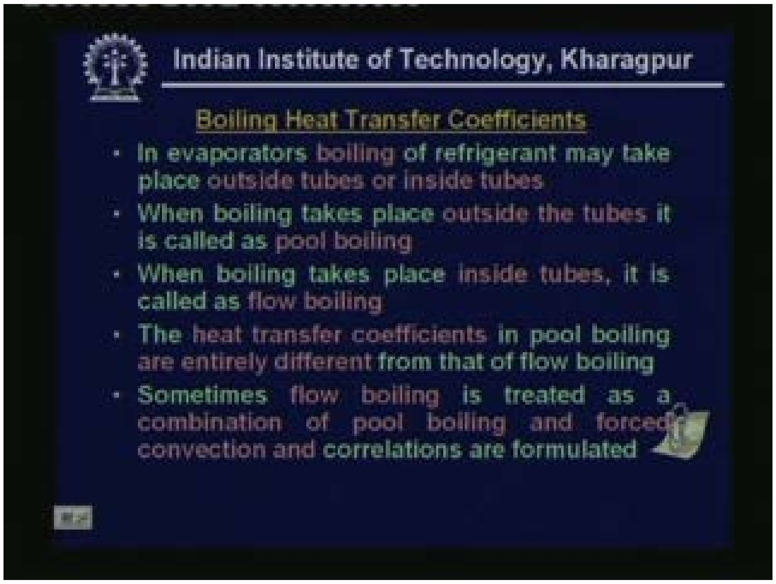

Direct expansion type shell-and-tube evaporator




Now let us look at liquid flowing in a shell this will happen in shell and tube type of evaporator with dry expansion where the refrigerant flows through the tube and liquid. That means water or milk flows through the shell in direct expansion type shell and tube evaporators. Refrigerant flows through the tubes while water or other liquids flow through the shell analysis of fluid flow. And heat exchanger on shell side is very complex due to the presence of large number of tubes baffles etcetera okay. So this is complicated again design point view because you can see that the large number of tubes again large number of baffels etcetera okay. So the prediction of heat transfer and pressure drop on the shell side is complicated because of the flow geometry okay. Several empirical correlations based on experimental observations have been developed over the years for predicting the pressure drop and heat transfer coefficients on the shell side. For example you have a simple correlation called as Emerson's correlation where the Nusselt number is given by hd by kf where kf is the thermal conductivity of the fluid being cooled. That is equal to C into R e to the power of point six prontle number to the power of point three multiplied by mew by mew w of point one four okay.

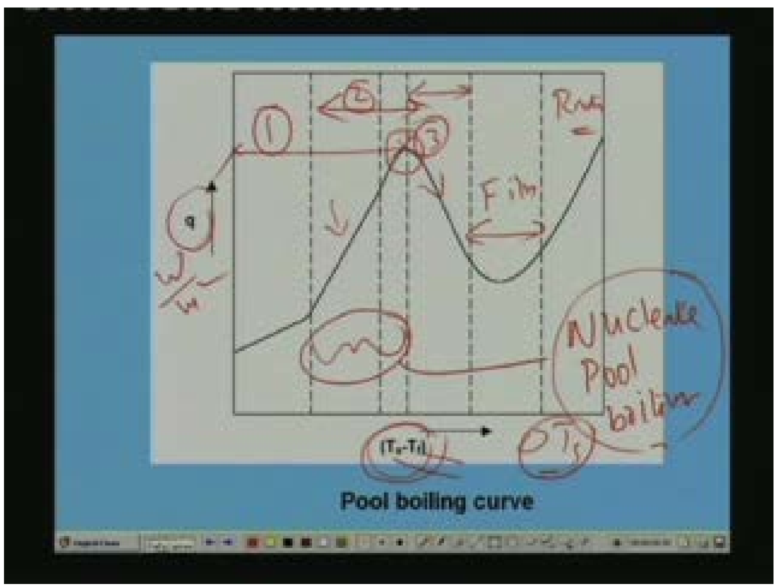
This looks almost similar to your sieder tate correlation for flow through tubes right. The viscosity effect is their Reynolds number is there and prontle number is their of course the exponents are different. Here we are use Reynolds number to the power of point six where as in case of flow through tubes we use Reynolds number to the power of point eight as long as the flow is turbulent okay. And in this expression the constant c depends on the geometry okay. That means how the baffles are placed and how many passes are there and all that okay. Depending upon the specific geometry of the shell and tube type of evaporator the constant of c has to be obtained and used okay. And the Reynolds number Red is defined as Red is Gd by mew where d is the internal diameter of the shell and g is the mass velocity which is equal to the mass flow rate divided by the characteristic flow area okay. So it has units of kg per meter squared per second. So find the Reynolds number from the flow rate and from the area of the or from the configuration of the shell and tube evaporator. Then from the Reynolds number and Prontle number find the Nusselt number.

(Refer Slide Time: 00:45:37 min)




Now let us look at boiling heat transfer coefficient. That means heat transfer on the refrigerant side in evaporators boiling of refrigerant may take place outside tubes or inside tubes. When boiling takes place outside the tubes it is called as pool boiling. You might have studied this in your heat transfer basic heat transfer course pool boiling when boiling takes place inside tubes it is called as flow boiling. The heat transfer coefficients in pool boiling are entirely different from that of flow boiling okay. Sometimes flow boiling is treated as a combination of pool boiling and forced convection and correlations are formulated based on this model.

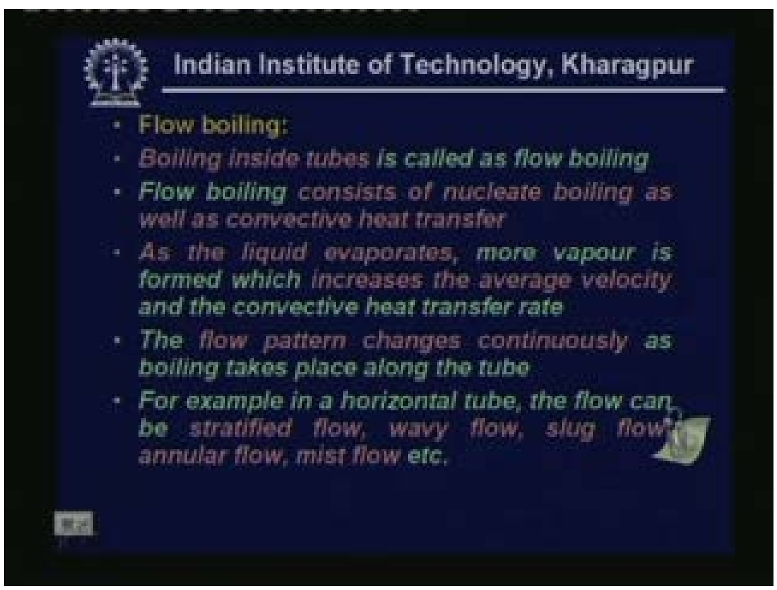
(Refer Slide Time: 00:46:21 min)


Let us look at some of the pool boiling correlations in pool boiling the tube or the heat transfer surface is immersed in a pool of liquid. Which is at its saturation temperature is, what you known as saturated pool boiling the heat transfer coefficient depends upon the temperature difference between the heat transfer surface and the boiling fluid. A pool boiling curve shows various stages of boiling and sure that this you must have studied in your basic heat transfer course. If you plot the pool boiling curve that means the heat flux okay, watt per meter square versus the super heat okay. That means the temperature difference between the surface ts is the surface tf is the fluid. And if you gradually increase the degree of super heat okay. You get a this kind of a curve right and you have different reasons here for example this region one is known as  natural convention region and this region is what is known as nucleat pool boiling region and this is your tangent boiling region.

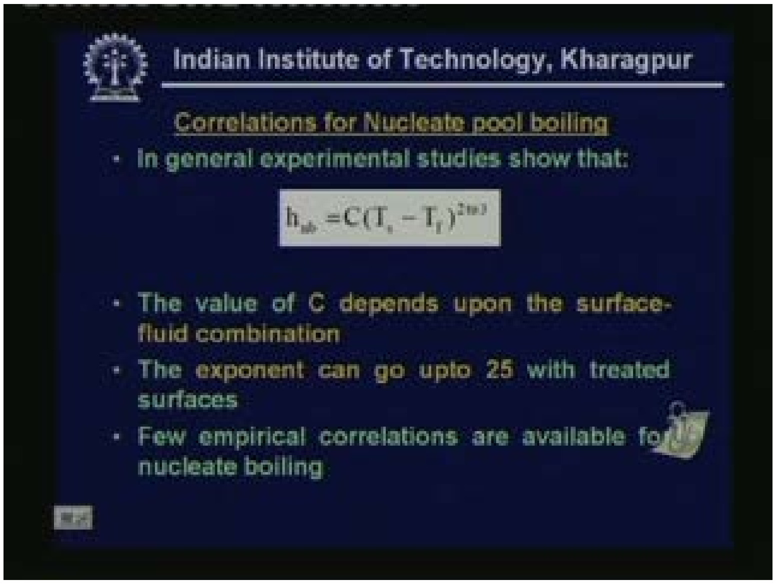
Then this you have film boiling okay. Then here the radiation comes into picture okay. So normally all the evaporators are boilers are designed to operate in this region okay. This is what you known as your nucleate pool boiling region okay. In this region you can see that the heat flux increases quite steeply with the degree of super heat delta ts. That means you get very high heat transfer coefficient in this nuclear pool boiling region oaky. And you can also have normally you have what is known as a critical heat flex at which the heat flux becomes maximum at a particular super heat okay. So if we increase the temperature difference beyond this  then the heat flux has to fall okay. And this point is also known as burnet point which you must have studied in the design of boiling okay. So as I said the refrigerant evaporators are design to operate in the nucleate pool boiling regions. So the correlations are available for this particular region. So as I sais this I have already explained.

(Refer Slide Time: 00:48:47 min)

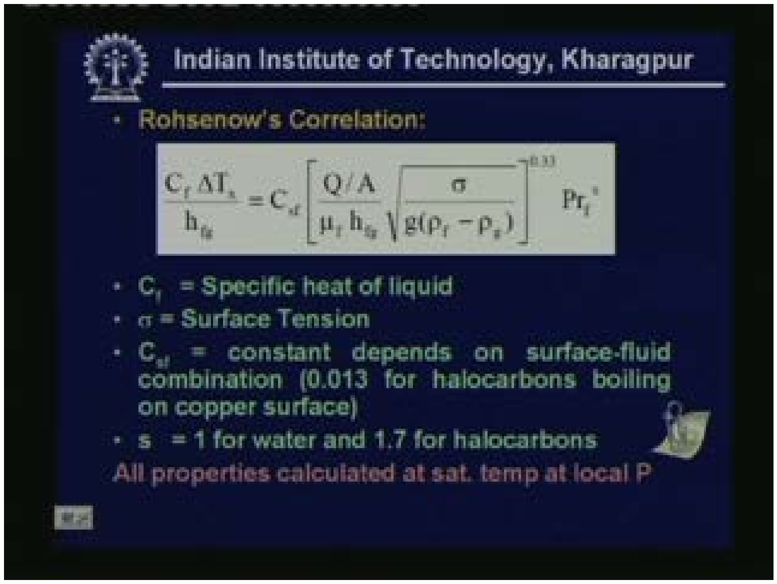



So now let us look at flow boiling inside tubes is called as flow boiling flow boiling consists of nucleate boiling as well as convective heat transfer. That means here the contribution to heat transfer comes from nucleate boiling as well as due to force convection. Heat transfer as the liquid evaporates more vapour is formed which increase the average velocity. And the convective heat transfer rate the flow pattern changes continuously as boiling takes place along the tube. For example in a horizontal tube the flow can be stratified flow wavy flow slug flow annular flow mist flow okay, depending upon the velocity of the vapour.

(Refer Slide Time: 00:49:27 min)




Now let us look at some correlations for nucleate pool boiling in general experimental studies show that the nucleate pool boiling heat transfer coefficient hnb is equal to some C into Ts minus Tf to the power of two to three okay, where Ts ia a surface temperature Tf is the fluid temperature. And C is the constant the value of which depends upon the surface fluid combination and the exponent. Even the, I have shown the exponent here as the varying between two to three it can go up to twenty-five with treated surfaces okay. The, that means with enhances surfaces you can get very high heat transfer coefficient. That means the exponent can go as highest twenty-five few empirical correlations are available for nucleate boiling okay. (Refer Slide Time: 00:50:16 min)

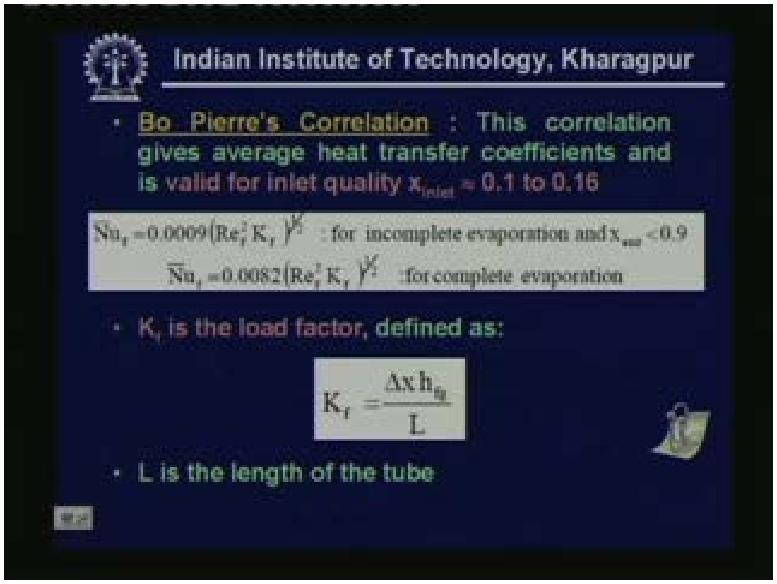



This is one of the okay, this is one of the popular correlation what is known as Rohsenow's correlation. So here Cf is the specific heat of liquid and delta Tx is the temperature difference between the surface and the fluid hfc is the latent heat of vaporization Csf is the constant which depends on surface fluid combination which is point zero one three for halo carbons boiling on copper surface oaky and Q by. A here is heat flux mew f is the viscosity of the liquid hfg is the latent heat of vaporization okay. Sigma is the surface tension g is the acceleration due to gravity row f and row j are saturated liquid and vapour density's trf is the liquid Prontle number. And the exponent s is one for water and one point seven for halocarbons and all the properties have to be calculated at saturation temperature at local pressure okay. So this is one of the oldest and very popular correlations for nucleate pool boiling.

(Refer Slide Time: 00:51:12 min)

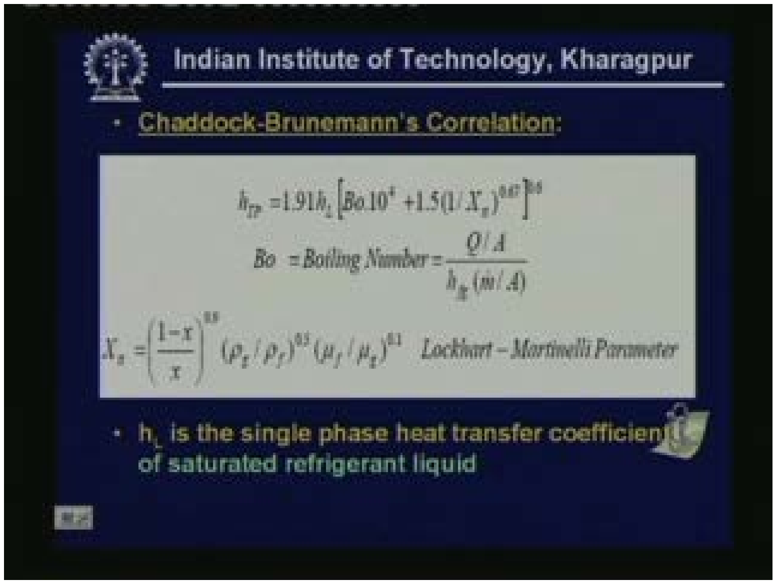

Now let us look at forced convection boiling inside tubes Rohsenow and Griffith suggested that flow boiling in tubes be analyzed as a combination of pool boiling and forced convection. That means they have obtained total heat flux q total is equal to q nb plus qfc where qnb is the heat flux contribution. Because of nucleate boiling and q subscript fc is the heat flux contribution. Because of force convection heat flux due to nucleate pool boiling is calculated by using nucleate pool boiling correlation. For example Rohsenow's correlation and heat flux due to force convection can be calculated by using standard force convection correlation such as Diitus Boelter correlation okay. So this is one of the simple way of handling flow boiling okay. But this is not very accurate okay, gives reasonably good result but not extremely accurate.

(Refer Slide Time: 00:52:01 min)



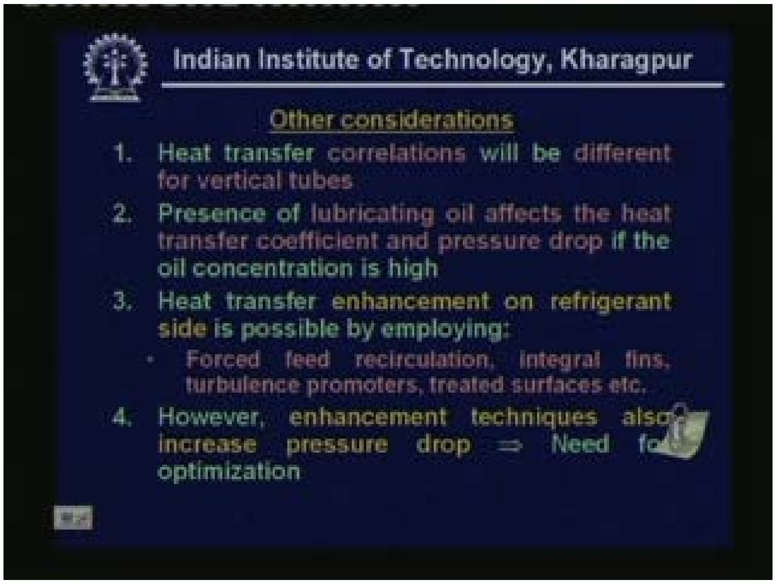

We also have what is known as the Bo Pierres Correlation which is normally used in refrigerants. This correlation gives average heat transfer coefficients and is valid for inlet quality x inlet varying between point one to point one six. That means at the exit of the exponential valve and at the inlet to the evaporator the refrigerant quality should be between point one to point one six. And the correlation is given here you can see that here the Nussel it is given for incomplete evaporation. And it also given for complete evaporation the constant is different constant is point three zeros nine for incomplete evaporation. And it is point zero zero eight two for complete evaporation. And here Ref is the Reynolds number based on the saturated liquid and K f is the constant and kf is called as a load factor and it is equal to delta X into hfg by L where hfg is the latent heat of vaporization delta X is the change in the quality and L is the length of the tube I am sorry kf is not a constant it depends upon the particular situation and also the fluid being evaporated.

(Refer Slide Time: 00:53:07 min)



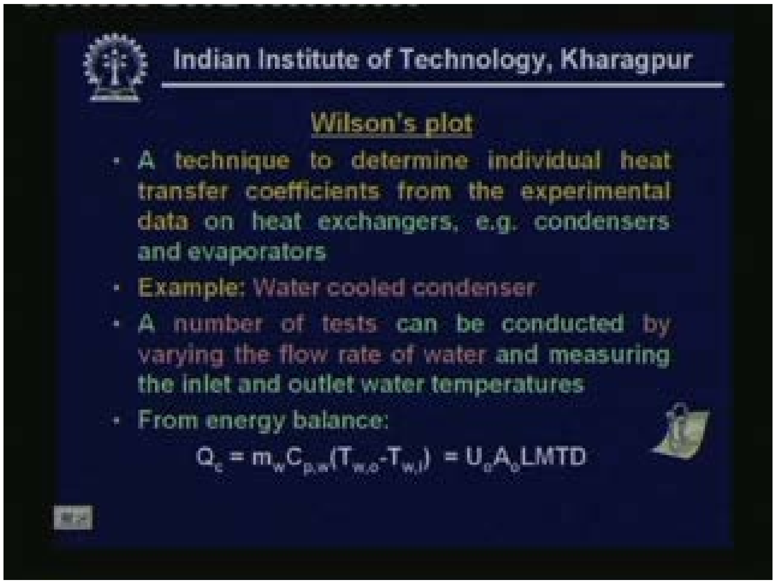

There is another correlation called Chaddock and Brunemanns Correlation. Again you can see the correlation here htp is the flow boiling correlation hL is the correlation a single phase heat transfer coefficient of saturated refrigerant liquid okay. And Bo is the boiling number that is given by Q by A divide by hfg into m dot by A where Q by A is the heat flux m hfg is the, as I said your latent heat of vaporization and m dot by a is a mass flux okay. And here x tt is what is known as Lockhart and Martimelli parameter and that is defined here and a xtt the small x stands for the quality row g and row f are the saturated vapour and liquid density's mew f and mew g are the saturated liquid and vapour viscosity's okay. So this is one of the correlations use for flow boiling of refrigerants.

(Refer Slide Time: 00:54:03 min)



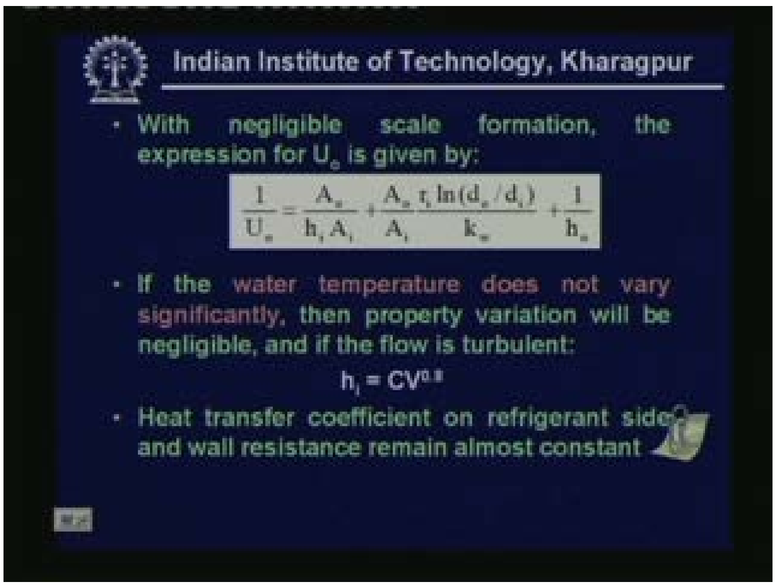

Okay, let us look at other considerations heat transfer correlations will be different for vertical tubes presence of lubricating oil affects the heat transfer coefficient and pressure drop if the oil concentration is high. Heat transfer enhancement on refrigerant side is possible by employing forced feed recirculation integral fins turbulence promoters treated surfaces etcetera. However enhancement techniques also increase pressure drop. That mean we have to optimize the enhancement techniques. So that you get high heat transfer coefficient at the same time the pressure drop is not very high okay. So this are the considerations.

(Refer Slide Time: 00:54:38 min)



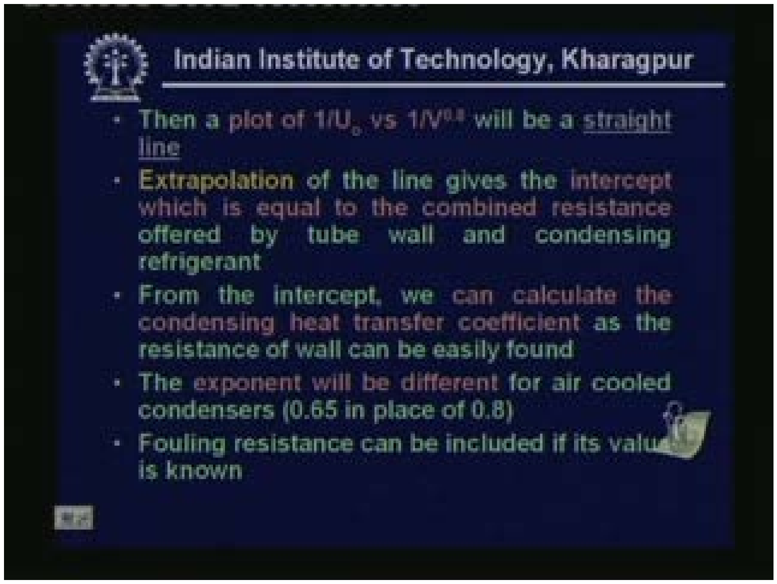
Now let us quickly look at what is known as the Wilsons plot this is the technique to determine the individual heat transfer coefficients from the experimental data on heat exchangers for example condensers and evaporator okay. So from the experimental data on these heat exchangers we can find individual heat transfer coefficients. For example take a water cooled condenser a number of tests can be conducted by varying the flow rate of water. And measuring the inlet and outlet water temperatures from energy balance we have this equation Qc is equal to m mw cpw into delta T for the water side which can be measured. And this is equal to U not A not into LMTD since LMTD can be obtained because we are measuring the temperatures A not is known.

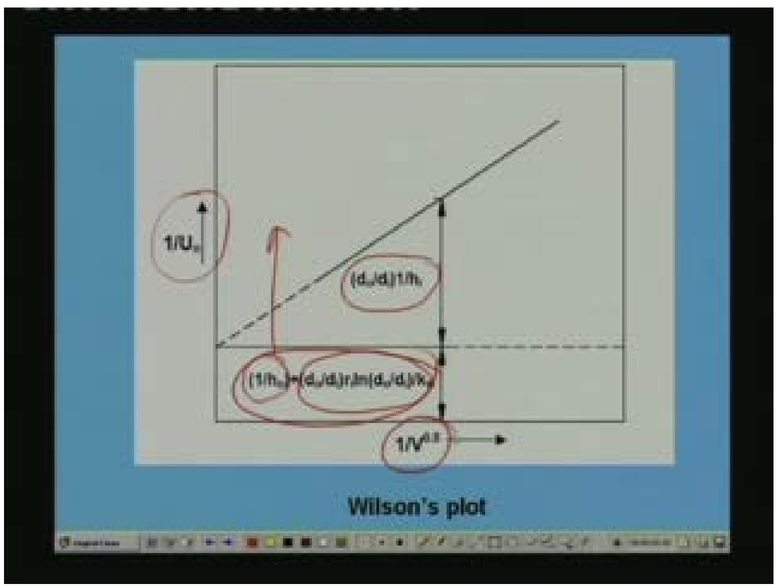
(Refer Slide Time: 00:55:26 min)




So form this expression you can find out the overall heat transfer coefficient from the experimental measurements with negligible scale formation the expression for U not is given here okay. This we have discussed in the last class this is the expression for U not and is the water temperature does not vary significantly then property variation will be negligible. And if the flow is turbulent then the internal heat transfer coefficient that is on the water side is proportional to V to the power of point eight. That means h i can be written as some C into V to the power of point eight okay. As long as the property variation is not, is not considerable and heat transfer coefficient on refrigerant side and wall resistance remain almost constant. Because we are not varying the refrigerant side flow rate or the operating conditions.

(Refer Slide Time: 00:56:05 min)




Then a plot of one by U not versus one by V to the power of point eight will be a straight line okay. So if you plot one by U not okay, versus one by V to the power of point eight then you get a straight line like this and the intercept gives you the resistance on the refrigerant side plus wall resistance. Because that remains constant where as the resistance on the water side will be varying because the velocity of the water is varying okay. From the intercept we can calculate the condensing heat transfer coefficient as the resistance of wall can be easily found the exponent will be different for air cooled condensers. That means for air cooled condenser it can be done with air or water or any other fluid. You have to use point six five in place of point eight fouling resistance can be included if it's value is known okay. This is the very useful concept and it is normally used for obtaining the condensing heat transfer coefficient etcetera okay. So at this I stop this lecture okay. So we are completed discussion of evaporators. So I will continuous this in the next lecture.

Thank you.