Process Equipment Design
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Lecture –23
Design of Condenser-2

Hello everyone. I welcome you all in third lecture of week 5 of the course Process Equipment Design and overall it is 23rd lecture where we are going to discuss design of condenser. So, if you see this topic we have started in 22nd lecture and it will be completed in 24th lecture. So, if you remember 22nd lecture there we have classified the condensers and the classification of condenser especially for shell and tube type.

So, as far as orientation is concerned and where the condensation is carried out based on that we have discussed the classification and then we have started elaborating the working of each type of shell and tube condenser. So, we have already focused on horizontal shell side condenser, so that part we have already covered in lecture 22 and here we will cover the next part as far as classification of shell and tube condenser are concerned. So, I am focusing on horizontal condenser when condensation is occurring in tube side.

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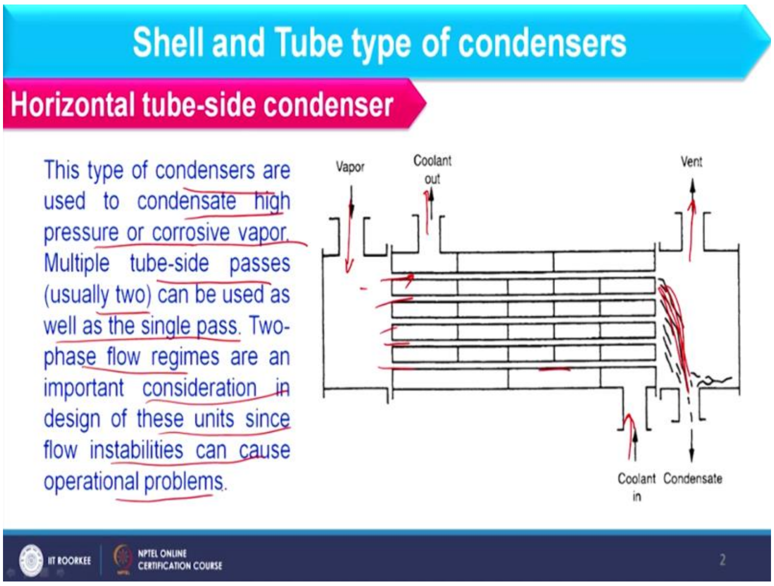

So, here you see I am having one schematic which you can understand as vapour is entering into tube side because here I am considering horizontal tube side condensation. So, vapour will enter in tubes and then from another side of the tube condensate exits. Now as far as baffle positioning is concerned, this baffle is basically normal baffle where I am having horizontal cut.

If you remember the horizontal condenser where condensation is occurring in shell side in that condenser we have discussed that baffles are usually having vertical cut because vapour movement is usually in this way, but in this case where condensation is occurring in tube side. So, shell side structure will be same as we have discussed in normal shell and tube heat exchanger.

So here we are having horizontal cut in baffles. So, further if you see when vapour is entering in tube side we have vent in a tube side, but at the opposite side of the tubes. So, this point also we have discussed in the last lecture that wherever the steam or vapour is entering into the system in the same side we usually place vent as well as steam trap. So, in this case coolant usually enter in shell side and exit from the another end of the shell side.

So, this type of condensers are used to condensate high pressure or corrosive vapour. So, as far as horizontal and vertical placement is concerned it depends on how much duty you are dealing with if duty is large you should select horizontal orientation. Now, the condensation side that either it should be shell side or it should be tube side it will depend on the nature of the vapour.

If nature of the vapour is corrosive, it should be allocated to tube side otherwise condensation we usually consider in shell side and the second option is if vapour is available at high pressure then it should be allocated to tube side because you understand that high pressure tubes are very cheap in comparison to high pressure shells. So that point we have already discussed in previous lectures.

So in that way you should select tube side condensation. So, multiple tube side passes usually two can be used as well as the single pass. Two phase flow regimes are an important consideration in design of these units since flow instability can cause operational problems. So 2 phase process or 2 phase regime we should consider properly because as vapour enters it is in a gaseous form or vapour form.

And as condensation proceeds, we have continuously formation of the liquid. So, instability may cause during the operation which we have to handle properly. So that is the horizontal tube side condenser.

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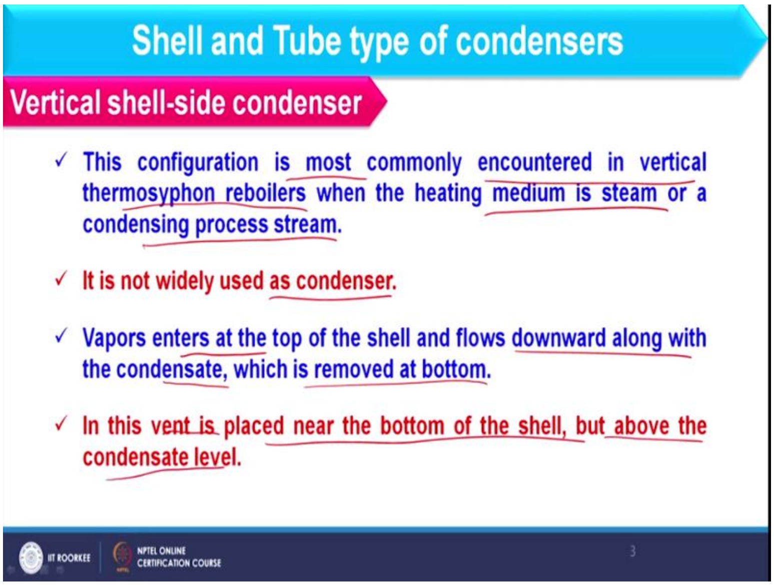

Now we will discuss vertical shell side condenser. So, you see this configuration is most commonly encountered in vertical thermosyphon reboilers. So instead of condenser, we consider vertical shell side condensation in thermosyphon reboiler. So, in that case boiling will occur in tube side. So, this point we will further elaborate when we will focus on the topic reboilers.

And if you remember the last lecture there we have discussed that condensation as well as reboiling process are just opposite to each other. So, this configuration is more suitable for reboiler and especially thermosyphon reboiler where heating media is steam or a condensing process streams. Next is it is not widely used as condenser. So, this point we should elaborate further in reboilers instead of condensers.

But we will discuss how to design such type of condensers and if you see further that in such type of condensers vapour enters at the top of shell and flows down along with the condensate which is removed at the bottom. So, if I ask you what is the usual movement of vapour because of less density the movement is upward obviously, but in this condenser we let the vapour enter from the top because what will happen when we let it enter from the bottom.

And when condensation will take place obviously the condensate will be collected at the bottom only because of its natural movement. So, at the bottom condensate is accumulated and it will block the movement of vapour from the bottom. Therefore, vapour enters from the top and as condensate proceeds the liquid as well as vapour both will move downward because when vapour is entering from the top vapour does not have any further space to move upward.

So definitely it will move downward with the condensate and condensate can be removed from the bottom. So, in this condenser vent is usually placed near the bottom of the shell, but above the condensate level.

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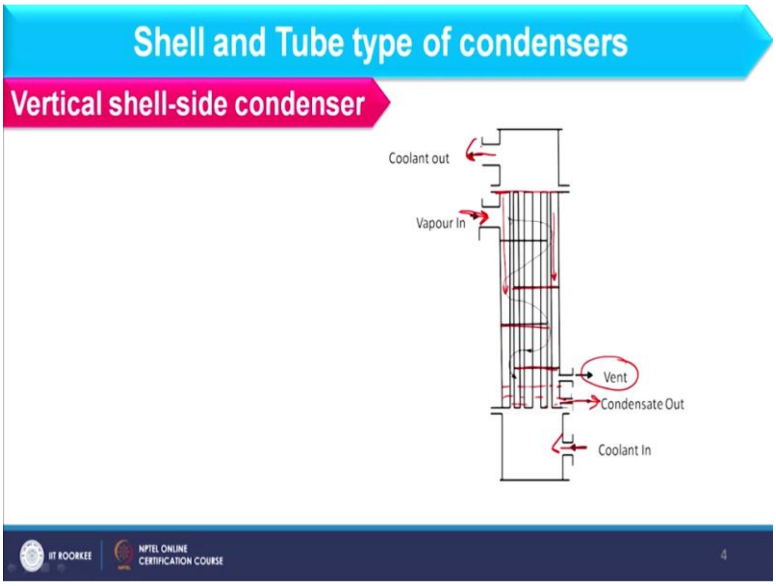

Now, if you see the schematic there you can understand it properly that vapour is usually enters from the top and it does not space to move upward because here we have end of the shell. So, vapour will move downward along with the condensate. Now in this case baffle cut is usual as we consider in normal shell and tube heat exchanger and as condensation process proceeds condensate moves downward.

And it is basically collected from the bottom and above that we have the vent nozzle because at the bottom we usually have condensate. So, we cannot place vent with the condensate it should be slightly above because vent is usually used to exit the non condensable gases. It is not made for condensate to come out.

To come out the condensate we usually consider steam trap as we have discussed in the last lecture and in this case coolant is usually enter into tube side and exits from the top. So, this is the basic functioning of vertical shell side condenser and further we will discuss vertical tube side condenser and as far as tube side condensation is concerned that is again with the same reason that if vapour is corrosive, we should place the vapour in tube side or if vapour is available at high pressure.

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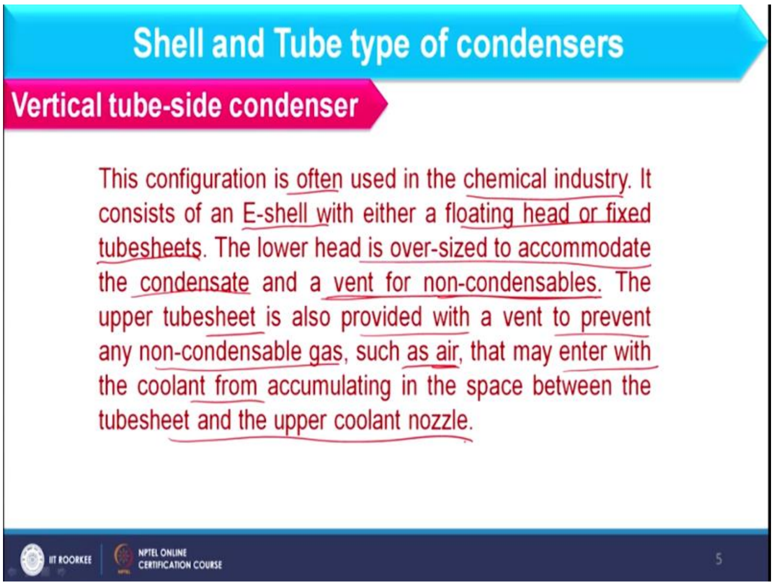

So, this configuration is often used in chemical industry. It consist of TEMA E-shell with either a floating head or fixed tubesheet. The lower head is oversized due to the accumulation of the condensate and vent for non condensable gases. So, if you see when I am considering vertical tube side condensation the condensate is collected from the bottom and at the same place we have to install vent nozzle.

So, the bottom section of this condenser is slightly oversized in comparison to the above section and that will be more clear when you will see the schematic in the next slide. So, the upper tube side is also provided with a vent to prevent any non condensable gases such as air that may enter with coolant from accumulating in a space between tube sheet and upper coolant nozzle. So, in this way we usually consider the design of vertical tube side condenser.

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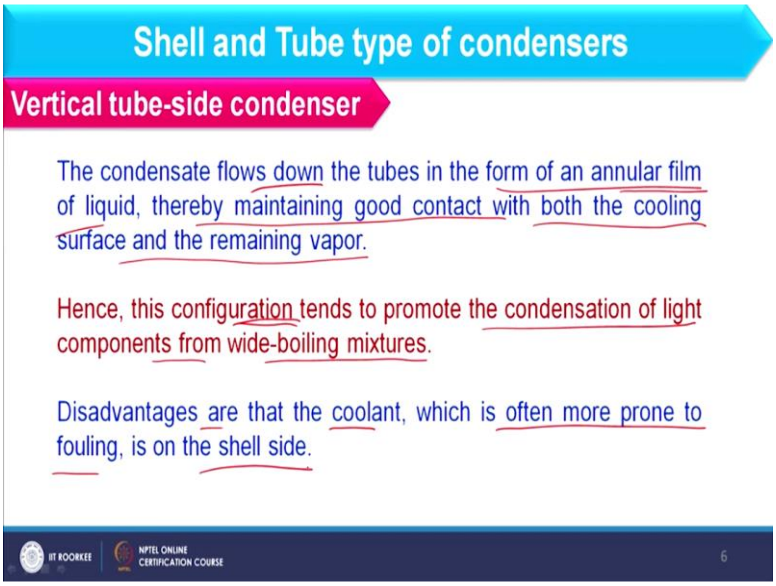

And further we have few more points about this such as the condensate flows down the tube in the form of an annular film of liquid and thereby maintaining good contact with both the cooling surface and the remaining vapour. So, when we consider the movement of condensate it is along the inner periphery because it is inside the tube. So, when it appears at the surface it is in better contact with the coolant which is available in shell side.

And with the vapour which is available in the annular space in the tube itself. So, this configuration tends to promote the condensation of light component from wide boiling mixture and as far as disadvantage is concerned disadvantages are that coolant which is often more prone to the fouling is on the shell side because we have considered corrosive vapour and that should be allocated to tube side.

But at the same time coolant must have some fouling tendency so it will create more dirt in shell side and that is the disadvantage because shell side cleaning is not easy in comparison to tube side.

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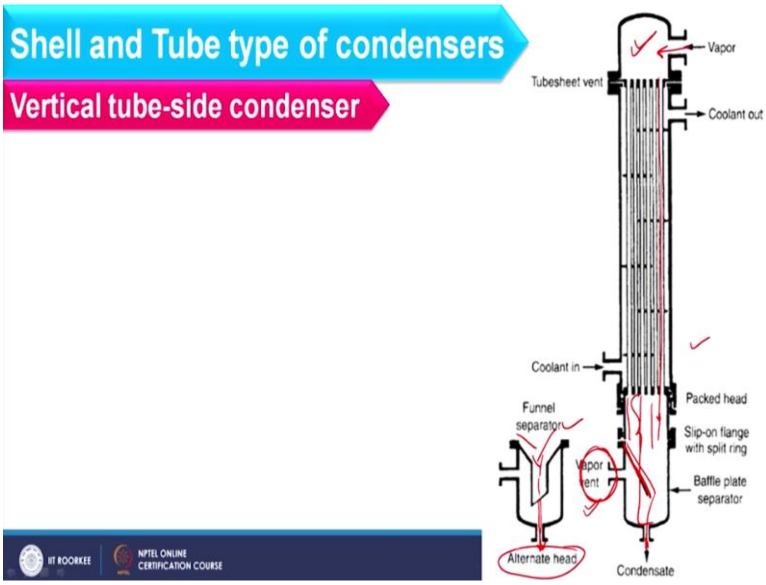

And now we will focus on the schematic. So, if you see the schematic of vertical tube side condenser vapour usually enters to tubes side from the top and moves downwards along with the condensate and if you see this section is oversized in comparison to this section where I am having condensate as well as the vent because vent is usually placed opposite to the side where vapour is entering.

So, in this case for proper discharge of the condensate we usually consider this type of assembly because whatever condensate is coming its slides over here and then exits from here and further it will not create any disturbance in the functioning of vent wall. So, in this way we consider the functioning of vertical tube side condenser and in some of the cases instead of this inclined strip we usually consider funnel separator where condensate is collected from here and directly exit from this head which we also called as alternate head.

So, in this way the movement of condensate and vapour occurs in vertical tube side condenser. So, you see we have discussed all types of shell and tube condenser and now we will compare these condensers based on some factors.

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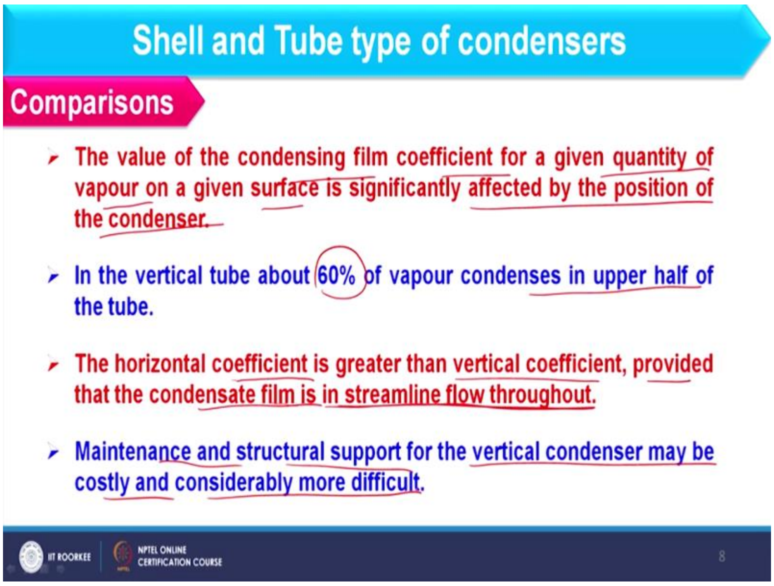

So, let us see the comparison. So, value of condensing film coefficient for a given quantity of the vapour on a given surface is significantly affected by the position of the condenser. So, we have to think properly about the positioning of the condenser, but basic parameter is it depends on the heat duty. So, in vertical tubes about 60% of vapour condenses in upper half of the tube and in horizontal case the horizontal coefficient is greater than the vertical coefficient provided that the condensate film is in streamline flow throughout.

So, usually we obtain higher coefficient in horizontal condenser because in vertical condenser the problem may occur because of the condensate accumulation and further we consider that maintenance and structure support for vertical condenser may be costly and considerably more difficult. So, if you see as far as maintenance is concerned and as far as support is concerned that we can handle properly in horizontal condenser instead of vertical because vertical condenser we have special type of support for that.

And as far as maintenance is concerned complete removal of the bundle in vertical condenser is difficult in comparison to horizontal because until unless you will not remove the bundle you cannot maintain the condenser because cleaning etcetera will be required when you take out the bundle from the shell. So, these are some points and accordingly you have to choose proper condensers.

Now, we will focus on heat transfer fundamentals of the condenser. Being a chemical engineer, you all have read about the condensation I mean the types of condensation. Usually we have two types of condensation, the film wise condensation as well as drop wise condensation and the film wise condensation the condensate form of film over the surface where condensation is occurring.

So, that film basically creates resistance in the path of heat transfer from coolant side to the vapour side. However, on the other hand if I consider drop wise condensation there droplets are formed over the condensate surface. So, it means resistance is not as much as we can see in film wise condensation because here droplets are there and in between space is empty. So, space will always available for vapour to condensate further.

However, that is not possible in film wise condensation until and unless I am not removing the film properly.

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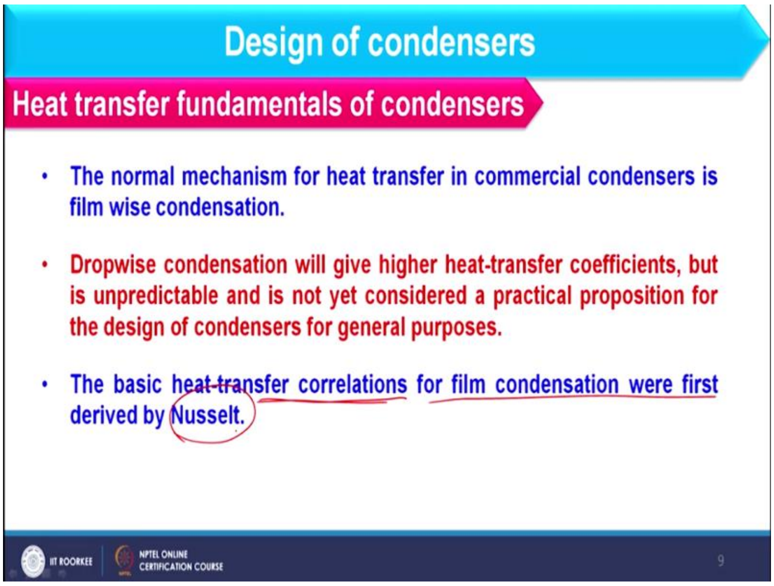

So, I hope all these fundamentals you know already and when we compare the film wise as well as drop wise condensation you should understand that heat transfer coefficient is more in drop wise condensation because of less resistance. However, the empirical correlations available for drop wise condensation is not as reliable as that is available for film wise condensation.

And therefore we are designing the condenser considering that film wise condensation is occurring not the drop wise and further the basic heat transfer correlation for filmed condensation was first given by Nusselt and therefore we will consider the equation or empirical correlations given by Nusselt.

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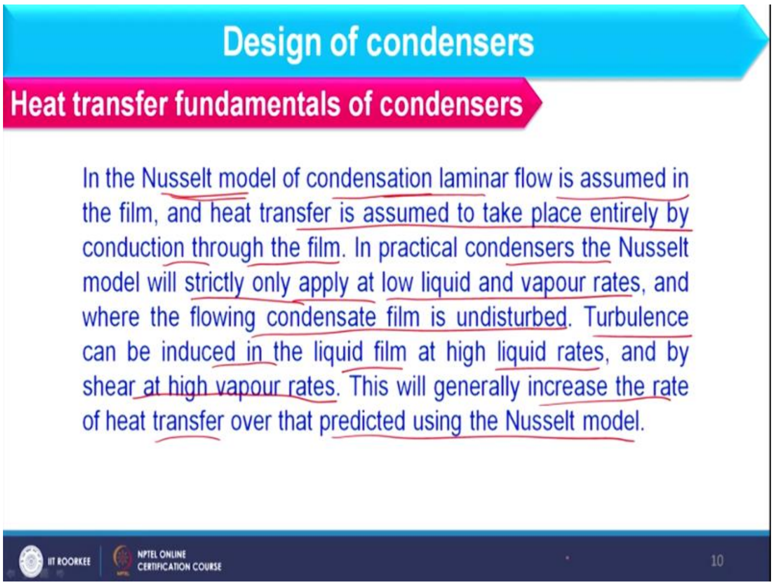

Further, if you see in the Nusselt model of condensation laminar flow is assumed in the film and heat transfer is assumed to take place entirely by the conduction through the film because we have the film and in this film we are not considering convection we consider that purely conduction will take place there. So, in practical condensers Nusselt model will strictly only apply at low liquid and vapour rates and where the flowing condensate film is undisturbed.

So, we have to consider laminar flow, we have to consider conduction mode of heat transfer. So, film should move uniformly at the surface so it should not be disturbed. Further, turbulence can be induced in the liquid film at high liquid rates and by shear at high vapour rates because vapour movement is available along with the condensate film movement and because of that some turbulence may occur because of the shear.

So, this will generally increase the rate of heat transfer over that predicted using Nusselt model, but more reliable model available to us is given by Nusselt only and therefore we will apply this model to design the condenser. So, let us start the design of condenser and here first of all we will focus on physical properties. If you remember the design of shell and tube heat exchanger, we will seen that physical properties we usually collect at average temperature.

But if I am considering condensation process, condensation process is usually isothermal because in that case only latent heat is transferred not the sensible heat. So, we usually have isothermal process so in condensation side we have only one temperature. So, how I should consider the average temperature to see the properties of fluids. To do that, we should basically average the condensate temperature as well as the temperature of the wall where condensation is occurring.

So, average of these two temperatures will give me the basis at which I should collect the physical properties, so that is about the physical property. Once you collect the physical property, we should go for design of condensers. Now, here if you consider the type of condenser these are basically shell and tube heat exchangers only and design of shell and tube heat exchanger we have already covered using Kern's method and Bell's method.

So, what we have to do over here where we will find the change in design. Now, you should see that whatever shell and tube heat exchanger we have discussed there we have considered the transfer of sensible heat because in both side we have found the change in temperature, but here in condensers we only transfer latent heat. So, wherever the condensation is occurring at that side we will have different phenomena of heat transfer in comparison to whatever we have discussed in shell and tube heat exchanger.

So as far as difference in design is concerned it is only based on the proper heat transfer coefficient which is corresponding to condensation process not the sensible heat transfer. I hope the fact is clear to you. So, based on that we will start design of condensers. I am not going into detail of each steps because all these steps we have already covered in shell and tube heat exchanger design wherever I am finding the change only that point I am considering here and that should be wherever condensation is occurring.

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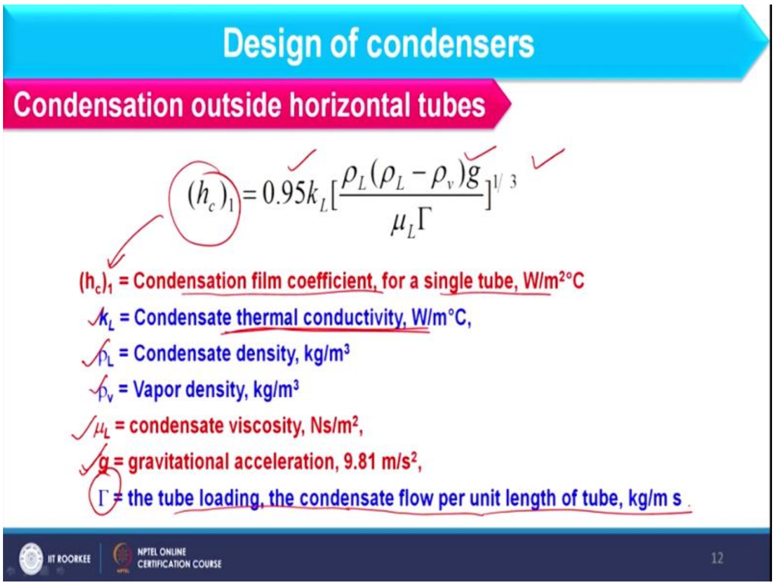

So, first of all let me focus on the condensation when it is occurring outside the horizontal tube. So placement is horizontal and condensation is in shell side. So, if you see for this case we have empirical correlation given by Nusselt and this is represented by h c 1 which is equal to 0.95 k L and the complete expression is shown over here. So, let me first focus on these parameters and then we will discuss this in detail.

So, if you consider h c 1 is basically the condensation film coefficient for single tube. So here what I am considering? I am considering that condensation is occurring only on a single tube. It means no other tubes are available. We have a single tube just vapour is passing over that and condensation is occurring. So, if you consider the complete bundle please understand it carefully.

If you consider the complete bundle that single tube will be available at the top of the bundle. It means it is the first tube which will be accounted by the vapour for condensation. So, therefore it is represented by h c 1. It is not considering the complete bundle, but only a single tube which is available at the top. I am repeating that again and again so that you should understand it properly.

So as far as other parameters are concerned we have k L that is basically condensate thermal conductivity rho L and rho v that is the density of condensate as well as vapour mu L condensate viscosity g is gravitational acceleration and I am having capital gamma also and this capital gamma is basically tube loading the condensate flow per unit length of the tube. So, tube loading is how much vapour you are handling per unit length of the tube.

So, this expression is only applicable for single tube. Now, let us focus on how it will be applicable for complete bundle. So to understand that, we should first focus on how condensation will move in the bundle.

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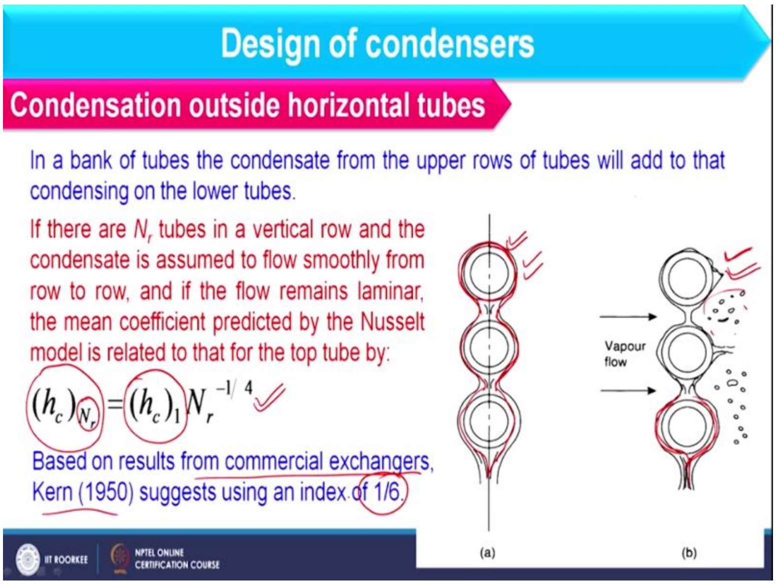

Now, if you see this schematic at the topmost tube I mean at the outer surface of the tube we are considering that as a single tube. So, condensation will occur over there and whatever condensate is formed it is basically joining the condensate which is available at tubes below to that in this way because when vapour is entering it will come across all the tubes. So, condensation will start over all the tubes, but as condensation will proceed we will have more thick film when I am considering lower tube rows in comparison to upper tube rows.

I hope it is clear to you and therefore what we can understand that if we move downward in the bundle the heat transfer coefficient of condensation will keep on decreasing and as I am having more and more thick film which will give more and more resistance. So, in this way whatever heat transfer coefficient we have considered over single tube it will not be able applicable until and unless I am not considering any correction factor.

So, this is based on smooth movement of the film however in actual sense movement of the film will be like this where I am having some vapour and some uneven film over the tube. Now, I am considering heat transfer coefficient as h c for N r and N r is basically number of tube rows in the bundle. So, it means here I am considering the bundle where N r rows are available and in that case whatever heat transfer coefficient we are considering for a single tube it should be reduced by N r power 1 over 4.

However, when I am considering more practical data I am having results based on commercial exchangers which are given by Kern and he suggested that the index should be 1

/ 6 instead of 1 / 4. So, because it is based on commercial exchanger we will consider N r power – 1 / 6 instead of 1 / 4.

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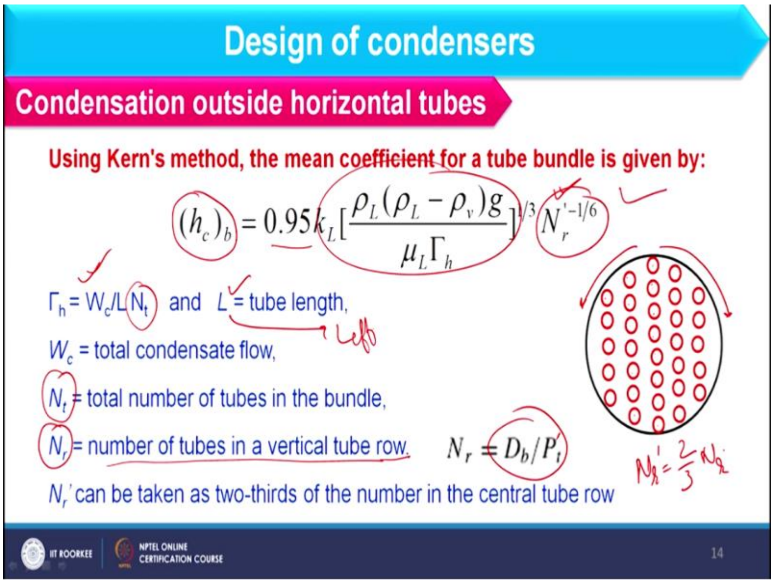

So, the final expression I am having is like this where N cb is shown where this is heat transfer coefficient for the bundle and it is 0.95 into the complete expression which we have already discussed and here I am having N r dash power 1 over 6. So, if you see here I am having another parameter that is N r dash here I am not considering N r. So, let me first focus on the parameters and then we will discuss what this N r dash is?

So, as far as gamma h is concerned h is loading that is tube loading W c / L into N t so it will depend on the condensate flow, length of the tube and N t total number of tubes because here I am considering per unit length. Now further you have to keep in mind that this L should be L effective because whatever portion of the tube is inside the tube sheet it will not participate in condensation process.

So, in that way you should consider L, N t we have already discussed, N r is basically number of tubes in a vertical tube row. So, what is this N r? When I am considering the central line of the bundle where I am having maximum number of tube rows so at that position I am considering N r. So N r is basically D b / P t dash here P t dash should be there it will depend on the type of arrangement which we have already discussed in previous lectures so here I am having N r.

Now if I consider this schematic N r is basically this if I keep on counting this. So, at the central line 1, 2, 3, 4, 5, 6, 7, 8 we have 8 N r. Now, if I move left side to this and right side to this we have less number of N r and that is very obvious because the (()) (31:02) will keep on decreasing from the center. So, in that case what I am considering h c b is basically counting N r at the center.

However, when I am considering the central line because of maximum N r we have least heat transfer coefficient at the center. However, that heat transfer coefficient will keep on increasing when I am moving to left side and right side of the central line because of less number of vertical tube rows and because of that we will have less thick condensate film. So, to average the complete bundle we consider N r dash as different parameters and that N r dash is basically 2 / 3 of N r which is available at the central line.

So, in this way you should consider N r dash for computing heat transfer coefficient in shell side of horizontal tubes and now I am focusing on condensation outside and inside vertical tube rows.

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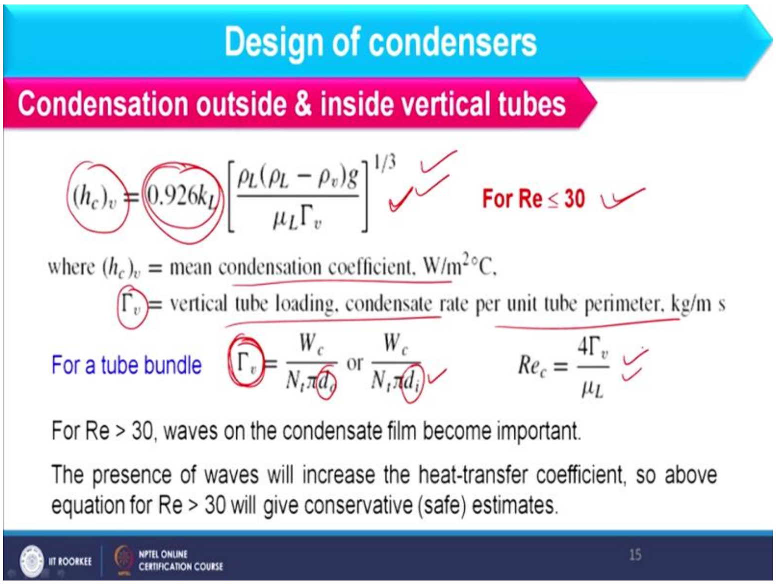

So, if you consider here I am having an empirical correlation and this is applicable for vertical tube rows. So, the expression is like 0.926 into different properties and here you see it is applicable for Reynolds number less than 30 where h c v is the mean condensate coefficient and gamma v is the vertical tube loading per unit periphery of the tube. For the tube bundle, we can consider gamma v which is equal to W c / N t pi d 0.

And we can again consider this as W c / N t pi d i. So, you see here I am having d 0 and here I am having d i based on that you consider different tube loading. However, you can consider same expression only tube loading differs and once I am having that tube loading I can find out Reynolds number based on this expression. So, if you see we can use the same expression for vertical condenser either condensation is occurring in tube side or in shell side.

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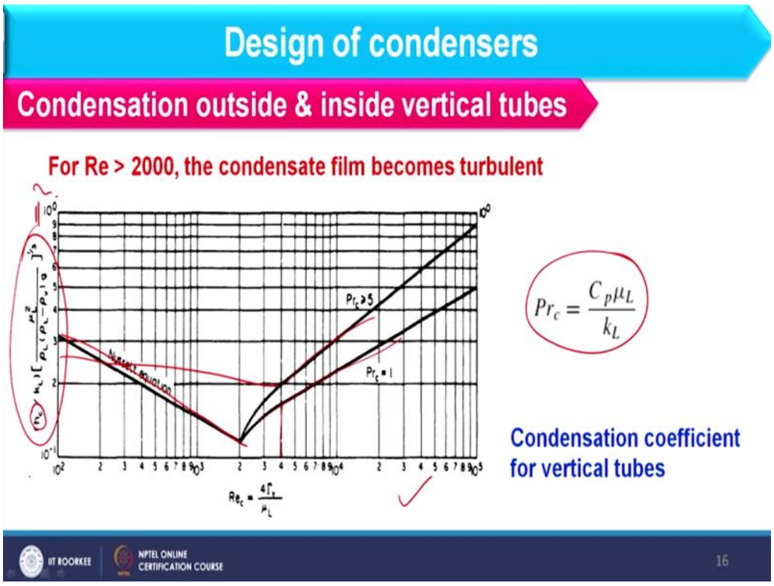

However, if I am considering Reynolds number in turbulent zone it means if Reynolds number is more than 2,000 we should consider this expression to find out heat transfer coefficient and here I am also having the Nusselt equation which is applicable below to Reynolds number 2,000 and after that it will depend on Prandtl number also. So, Prandtl number you can find out by this.

So, here depending upon the Reynolds number and Prandtl number you can find the value of this factor and whatever value you can obtain it will be equal to this and when you will solve this you can find h c which is the heat transfer coefficient in vertical tube side or shell side condensation.

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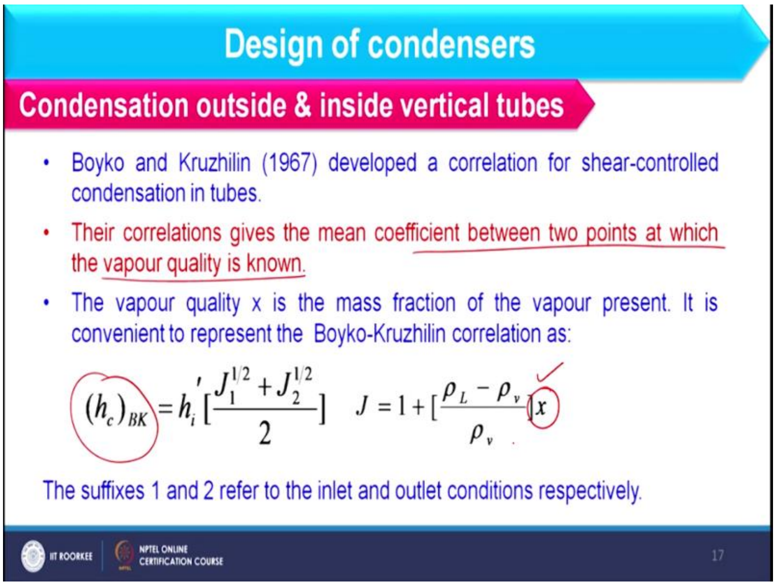

Now, next is we have another correlation which is given by Boyko and Kruzhilin and which is applicable to find out heat transfer coefficient inside the vertical tube. So, for inside you can use this equation as well as whatever graph we have discussed in the last slide. So, Boyko and Kruzhilin gives a correlation and that will depend on the two points at which vapour quality is known.

Two points means where vapour is entering and from where condensate is exiting. So, vapour quality is what how much mass of vapour is available. So that we usually represent by quantity x so that is basically the vapour quantity so when I am considering the vapour which is entering into the condenser we consider that it is available at saturation condition. So, in that case x value is usually 1 because whole feed is vapour.

And when the complete condensation occur we consider x as 0 otherwise depending upon the level of condensation we find out the x value accordingly. So, we have Boyko Kruzhilin correlation as like this where h c BK is shown as h i dash J 1 and J 2 / 2. So, J we can consider by this which will depend on the vapour quality. So, J 1 and J 2 are basically at inlet and outlet of the condenser.

Now what is h i dash? h i dash is basically the heat transfer coefficient for a single phase of condensate where I am considering that only condensate is moving inside the tubes.

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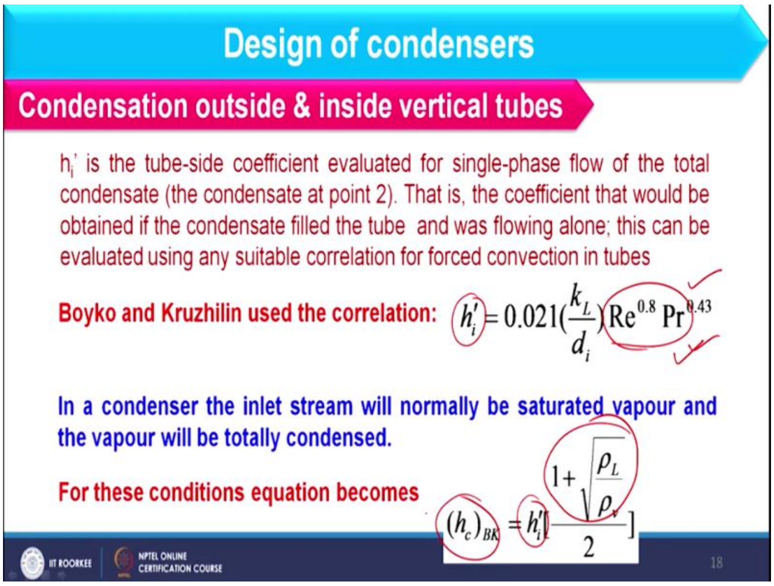

So for that case Boyko Kruzhilin consider the expression of usual heat transfer coefficient which you also have seen in sensible heat transfer and this is given by h i dash and this expression you can use which is the function of Reynolds number and Prandtl number and when I am considering that saturated vapour is entering and complete condensation is occurring at the end of the exchanger.

We find that J value we can simply represent by this expression. This is J 1 and J 2 expression and h i dash you can compute using this equation. So, in this way we can find out Boyko Kruzhilin correlation.

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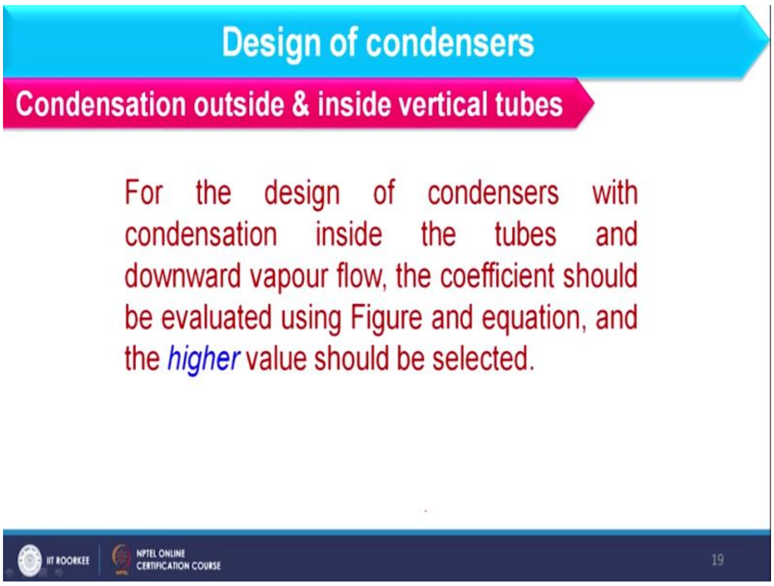

So, when I am considering inside vertical tube condensation you have to find out heat transfer coefficient using the graph as well as Boyko Kruzhilin correlation and consider the higher value of heat transfer coefficient as the final value. So, I hope design is clear to you. We will continue the design of condenser for other orientation in next lecture so that is all for now. Thank you.