Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology – Roorkee

Lecture –24
Design of Condenser-3

Hello everyone. Welcome to the 24th lecture of the course Process Equipment Design and here we are in 5th week of this course and we will discuss design of condenser in this lecture. So this topic I have already started in 22nd lecture and we also have covered that in 23rd lecture and in this lecture we will end this topic. So, if you remember in 22nd lecture we have discussed the classification of condensers and that we have continued in 23rd third lecture and in 23rd lecture we will start design of condensers.

And here we will extend the design of condenser further. So, let us focus on design of condenser when condensation is occurring inside the horizontal tube. We have already covered the design of condenser where condensation is occurring in shell side of horizontal condenser and shell side and tube side of vertical condenser. So, let us discuss when condensation is occurring inside the horizontal tube.

Here, condensation occurs in horizontal tubes and the heat transfer coefficient at any point along the tube will depend on the flow pattern at that point because what will happen in horizontal tube that vapour enters from one end of the tube and it keeps on moving towards another end. So, what will happen as condensation proceeds we have maximum amount of vapour at the start of the tube.

And we have maximum amount of condensate at the end of the tube. So, continuously pattern is changing and that pattern remain at that position because what will happen in vertical tube condensate will keep on falling. So, condensation accumulation is usually occur at the bottom of the vertical condenser. However, in horizontal condenser that accumulation in maximum amount is occurring at below surface of the tube inside the tube.

So, it will offer more and more hindrance in the path of condensation. So, in such condensers the heat transfer coefficient will depend on the flow pattern inside the tube.

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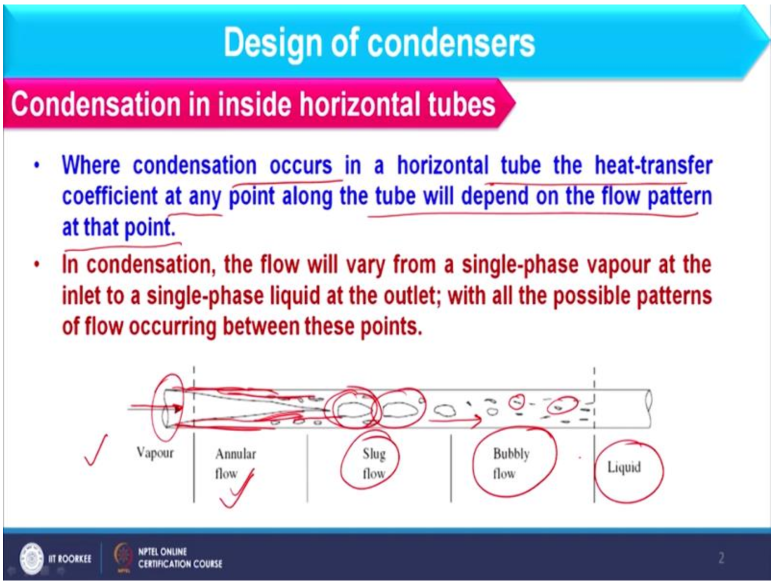

So, let us discuss the pattern inside the horizontal tube and that you can understand through this schematic when the fluid is entering or we can say when the vapour is entering in the tube it is at pure vapour form and when it will come across with the surface which is available at lesser temperature than the vapour condensate will start from this surface only and here you see we have the condensation formation and as we proceed further we can find that condensate film thickness will keep on increasing.

So, this section we basically call as annular flow because at the periphery of the tube we have condensate film and at the center we have vapour. So, that is a form of annulus and when we move further and condensate proceeds then what will happen we have big size of bubbles and because complete condensation is not occurring however condensation will be more in comparison to vapour therefore vapour will be available in bigger size bubbles.

And when I am considering the size of these bubbles the diameter of these bubble is equal to the inside diameter of the tube. So, it will basically give envelope in the tube and then the movement will start from the condensate side. So, what will happen because of this envelope continuously fluctuation is occur in the flow of the condensate and therefore we call this as a slug flow and further when we move ahead we can have more and more condensate.

So, bubble size will keep on reducing and this flow we consider as a bubbly flow and after that we have complete condensate which is purely in liquid form. So, you can see from the pure vapour to the pure liquid different patterns are changing as we have just discussed and this is happening only in the horizontal tube. So, how to consider this pattern in design of condenser.

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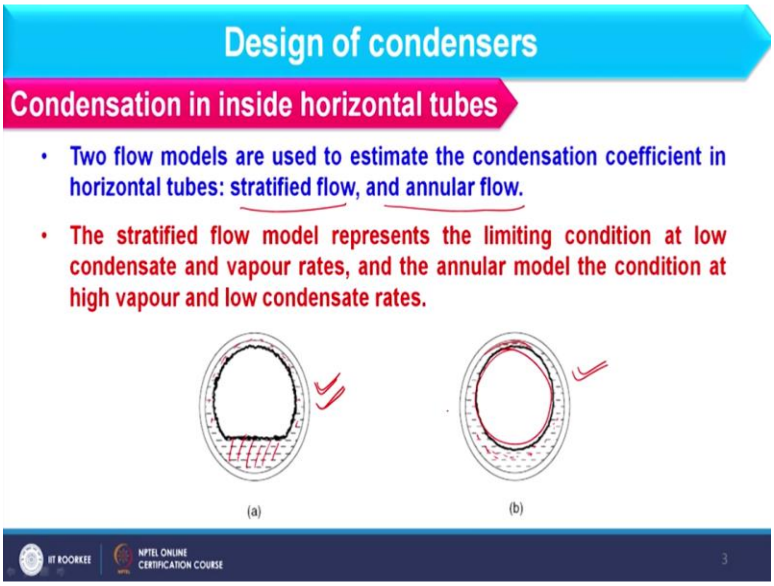

To consider that, we can have two models and first model is the stratified flow and second is the annular flow and when I am considering stratified flow it is basically looking like this where more condensate is available at the bottom and less condensate is available at top of the inner surface of the tube and this will happen when I am having lesser flow rate of vapour as well as lesser flow rate of condensate.

So, more and more condensate will occur at the bottom because of the gravity effect and therefore the heat transfer coefficient will be less at the bottom and more at the top when I am considering inner surface of the tube. On the other hand, if I am considering annular model in that case though we have more thick condensate at the bottom in comparison to top, but the flow is like annular.

And this will happen when I am having lesser flow rate of condensate and more flow rate of vapour. So, vapour will pass as a jet and it will make the annular flow as we have just discussed. So, considering these two models we will find out heat transfer coefficients inside the horizontal tube. So let us discuss that part.

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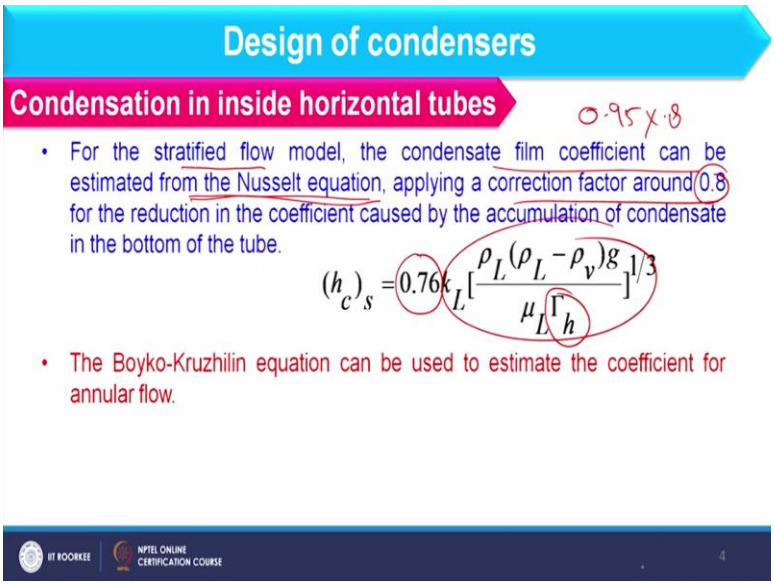

So for stratified flow model the condensate film coefficient can be estimated from Nusselt equation and what was the Nusselt equation when I was discussing horizontal tube condenser where condensation is occurring in shell side. So, if you remember there we have discussed one expression like heat transfer coefficient is equal to 0.95 into some properties so the same equation you can use over here.

However, because of the variation in condensate film thickness we should consider some correction factor and that correction factor is usually 0.8 so if you consider 0.95 into 0.8 we can have the correlation like 0.76 into the properties by considering tube loading also. So, 0.76 is basically 0.95 into 0.8 and here we should consider that we can obtain slightly lesser heat transfer coefficient in comparison to Nusselt equation.

And the reason is very simple because I am having variation in the thickness of condensate film inside the tube and further if I am focusing on annular side flow in that case you should consider Boyko Kruzhilin correlation which we have discussed in the last lecture. So that Boyko Kruzhilin correlation can be used here also. So, here I am having stratified flow as well as annular flow.

So, here you have to find out heat transfer coefficient using both models and you should choose higher value of heat transfer coefficient as final value when condensation is occurring inside the horizontal tube. I hope this procedure is clear to you and why I am considering both flow because when the flow is occurring inside the horizontal tube you cannot predetermine that which model is applicable.

So, you have to use both model and choose the higher value of heat transfer coefficient as the final value. So, in this way we complete the design of condensers of shell and tube type and further we will discuss few more points.

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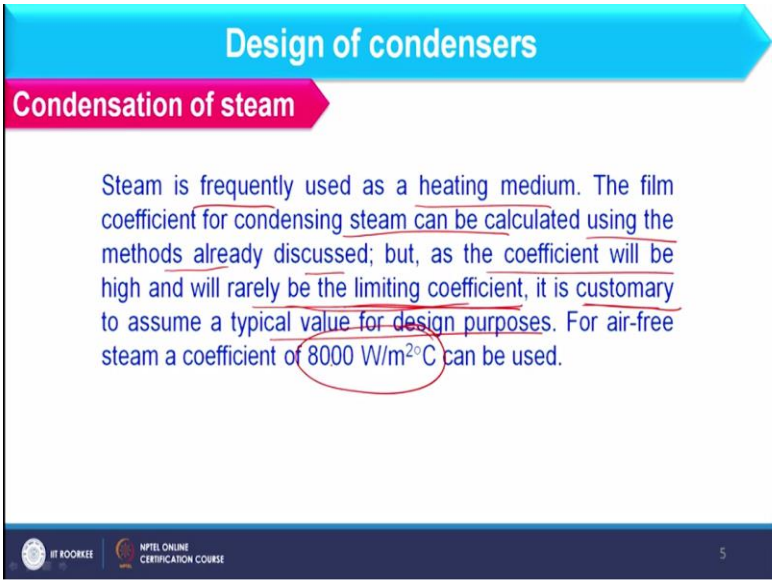

And here we have condensation of steam. Now steam is frequently used as a heating media and the film coefficient for condensing steam can be calculated using methods already discussed, but as the coefficient will be high we rarely be the limiting coefficient it is customary to assume a typical value for design purpose because condensation of steam coefficient will be higher in comparison to whatever methods we have discussed.

So, usually we consider a typical value which is around 8,000 watt per meter square degree Celsius as the coefficient of the steam. So, you should keep in mind what you are considering as a feed it is vapour or it is steam and accordingly you have to choose the coefficient value.

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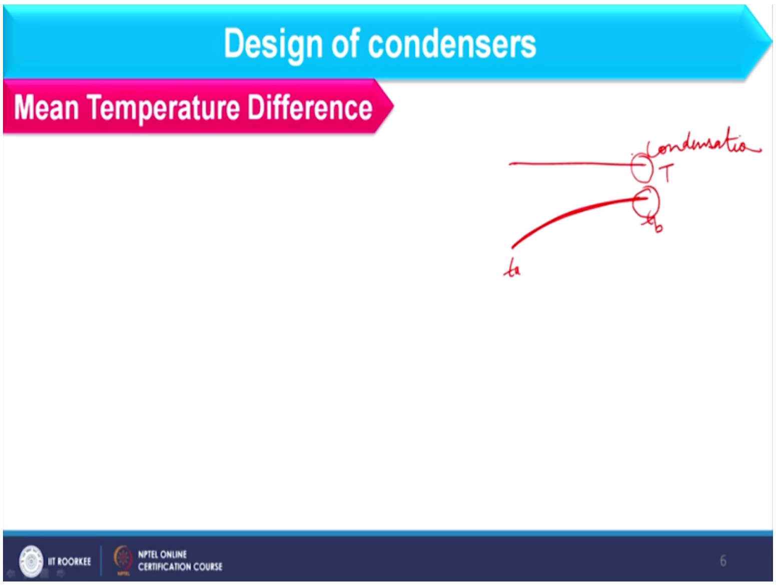

And now we will focus on mean temperature difference because when you are going to design a condenser you have to calculate heat transfer coefficient you need mean temperature difference and then only you can find out the area. As far as mean temperature difference is concerned, we have different points over here. So, if I am considering pure vapour. So condensate will occur at isothermal condition.

However, the coolant temperature will keep on varying. So, if you see when I am considering pure vapour in that case only condensation will occur and that should be at constant temperature and this condensate will give its heat to the coolant. So, coolant temperature should be available below. Now as coolant is having a sensible heat transfer its temperature will keep on changing from inlet to outlet.

However, temperature will not change in condensation side. So, what will happen if this is t a and this is t b what will happen? In this case, the exit temperature of coolant will never be more than the saturation temperature of condensate. So, in this case how you have to find out mean temperature difference you should consider log mean temperature difference.

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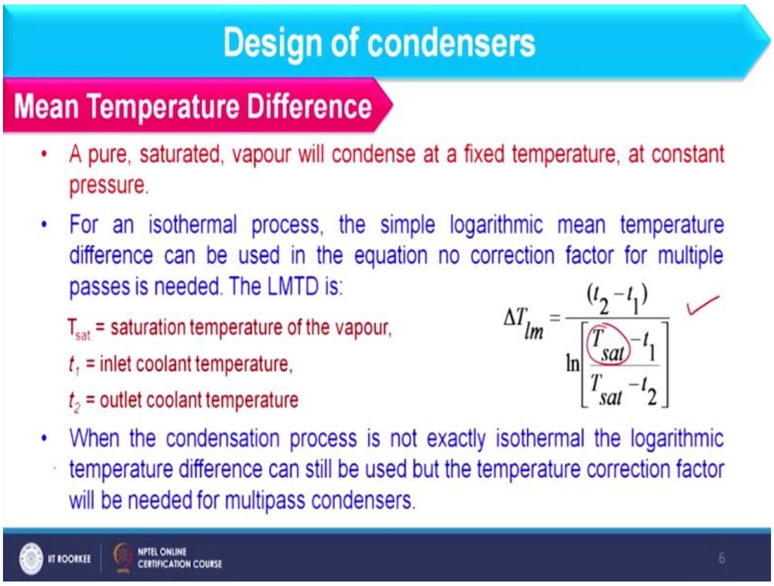

So, here T saturation it means the temperature of condensation and t 1 and t 2 are inlet temperature and outlet temperature of the coolant. So, in this way you can find out LMTD irrespective of the counter current flow and concurrent flow and further if I am asking that instead of pure component if I am having mixed vapour then how the condensation will proceed.

In that case condensation will not anymore as an isothernal condition and the reason is very simple because if I am considering the mixed vapour each component which is available in that mixture has different dew points and accordingly we can have different temperature at which condensate of each component will be obtained. So, in that case we can have non isothermal condition in condensation side along with the same non isothermal condition in coolant side.

So, in that case if you see the profile it will be like this when it is concurrent and it will be like this when it is counter flow pattern. So, in that case we may get the chance where temperature cross occur. We may get the chance where I am having the temperature cross and if this will happen it will not be good for design of condenser. So, if this is the case you should consider LMTD along with F t correction factor.

So, F t correction factor we should consider where I am having non isothermal in both side shell side as well as tube side and the reason is very simple that here we have the chance to get the temperature cross. So, you have to consider the mean temperature difference accordingly. I hope it is clear to you.

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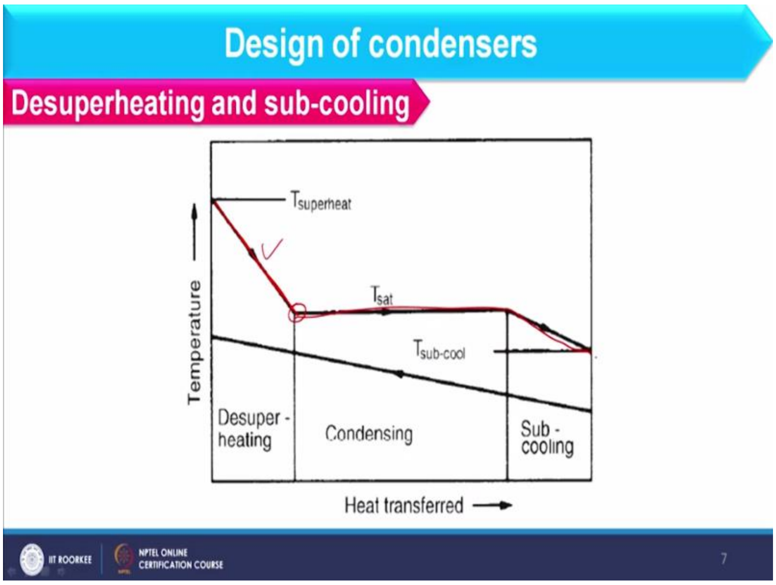

And next we will consider another factors about condenser. Usually whatever expressions we have discussed that is based on condensation process only. However, in actual industry what will happen when the vapour is exiting from a particular equipment and entering into the condenser it pass through a complete pipeline. So, in that pipeline heat loss must occur and when the vapour is entering into the condenser it should be at saturation condition otherwise condensation will start in the pipeline only.

To ensure that the vapour should enter in the condenser at saturation condition we keep the vapour at little bit higher super heating condition. So, in that case vapour will be available at super heated condition and because of the heat loss when it is entering into the condenser it should reach to the saturation condition. Now what will happen when vapour is available at super heated condition?

First, desuperheating will take place and which is a non isothermal process because at that point it will transfer sensible heat and when it will reach to the saturation condition then the condensation will proceed and after that we can obtain certain amount of sub cooling also because after that the condensate may go to the storage vessel where a particular temperature is required, so we can have some amount of sub cooling also.

So, if this is the condition that instead of condensation only we will have desuperheating, we will have sub cooling here how we should account all these factor in design of condenser. So, let us start with desuperheating.

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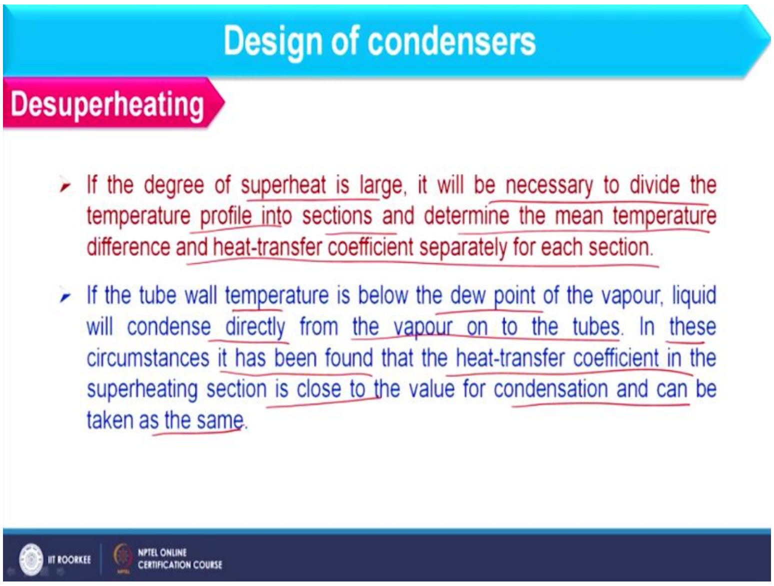

So, if degree of superheat is large it will be necessary to divide the temperature profile into sections and determine the mean temperature difference and heat transfer coefficient separately for each section. So, if degree of superheat is large how much large? It should be more than 25% of the latent heat which is involved in condensation process. So, if degree of superheat is large we have to consider design of de superheater as well as condenser separately we have to find out temperature difference and heat transfer coefficient in these section separately and then we have to club them based on (()) (17:48) heat.

And if the tube wall temperature is below the dew point of the vapour liquid will condense directly from the vapour on the tubes. So, it will also depend on that what should be the temperature of the coolant and in these circumstances it has been found that heat transfer coefficient in super heating section is close to the value for condensation and can be taken as it.

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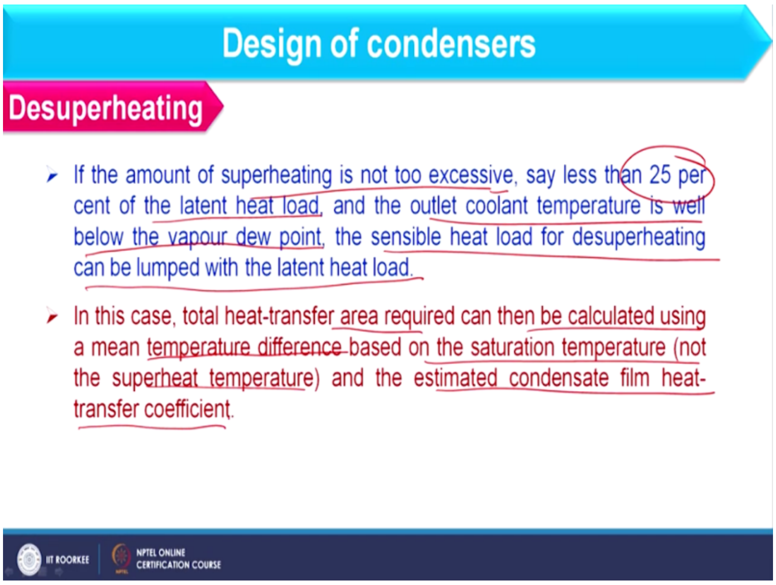

And further we should consider the case where superheating is not much. So, if the amount of superheating is not excessive let us say it is less than 25% of the latent heat load in condenser and the outlet coolant temperature is well below the vapour dew point the sensible heat load for desuperheating can be lumped with the latent heat load. So, if desuperheating amount is less than 25% of the latent heat we should add that load into latent heat.

And design the condenser based on the total heat load and in that case how we should count the heat transfer coefficient let us see that. In this case, the heat transfer area required can be calculated using mean temperature difference based on saturation temperature not the superheated condition and we can further estimate the condensate film heat transfer coefficient.

So you should consider the total heat load which includes latent heat as well as heat of desuperheating we have to find out mean temperature difference of saturation condition and then we have to estimate the heat transfer coefficient according to the condensation process. So, in this way we should account desuperheating and now we should focus on subcooling.

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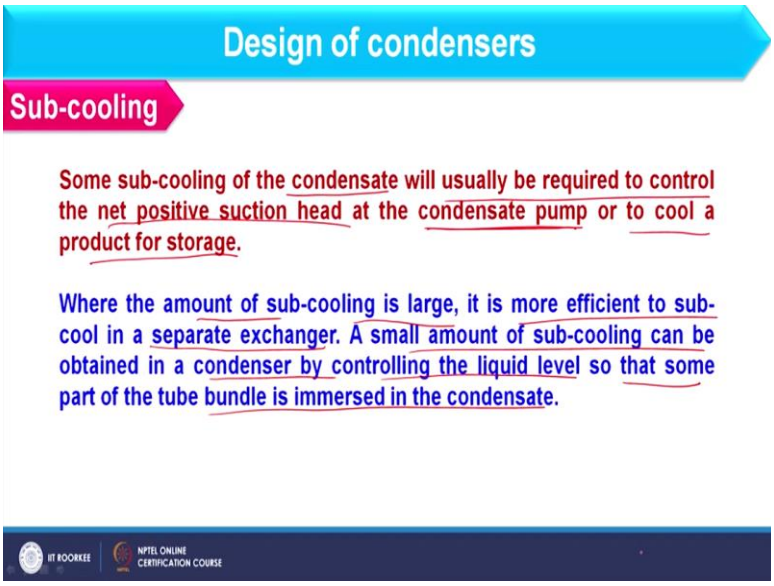

So as far as sub cooling is concerned some sub cooling of the condensate will usually be required to control net positive suction head at the condensate pump or to cool down the product for the storage. So, here you can observe that some sub cooling we do intentionally because after that we have to pump this condensate to the storage tank or some other equipment and for that purpose we need pump.

So, pump cannot be operated if I am not ensuring that the feed is entirely liquid. So, to ensure that some sub cooling should be there. Now, if I ask you that what should be the temperature of the condensate? Usually when condensation process is carried out of the pure component the condensate temperature will be equal to the vapour temperature because there we have only the phase change.

However, if you have carried out experiment on condenser and if you have measure the temperature of the condensate that temperature is slightly lesser than the vapour temperature though difference is not much one or two degree, but condensate will have lesser temperature than the vapour temperature and that is due to the heat loss and industrial condenser we usually consider some amount of sub cooling because we have to ensure the performance of the pump.

So where the amount of sub cooling is large it is more efficient to sub cool in a separate exchanger as we have discussed in superheating also. A small amount of sub cooling can be obtained in a condenser by controlling the liquid level so that some part of the tube bundle is emerged in a condensate. So, here we should ensure that if amount of sub cooling is not much we have to design the condenser.

And in that case some tube which are available at bottom section of the condenser that should be emerged in a condensate. So to ensure that some of the tubes of the bundle should be merged in a condensate we use special type of baffles.

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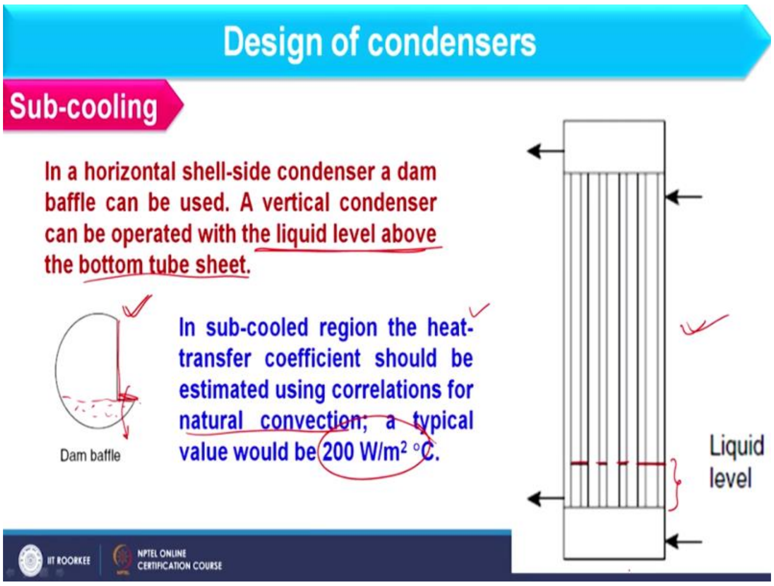

And for vertical condenser we usually consider dam baffle where the design is like this because in vertical condenser we usually have vertical cut and this section we provide to ensure that this much tube should be merged in a condensate and beyond that the condensate will keep on leaving the system. It means the heat exchanger must have certain amount of condensate always when I am considering sub cooling.

So, this design is applicable for horizontal shell side condenser and when I am considering vertical condenser we should ensure that some liquid level should be maintained above the bottom tube sheet. So, if you consider this schematic we should ensure that some liquid should be available at the bottom and therefore we can consider sub cooling accordingly. So, here if sub cooling is not much you can simply add the load of sub cooling to the condensation side.

So in sub cool region the heat transfer coefficient should be estimated using correlation for natural convection which is having a typical value of like 200 watt per meter square degree

Celsius. So in this way we can consider desuperheating as well as sub cooling in the condenser.

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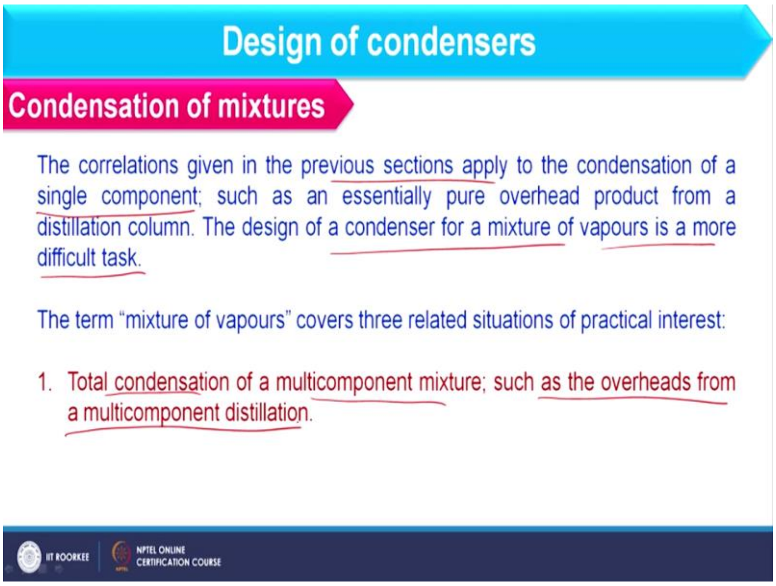

Now, we will discuss few more points for the condensation of the mixture so let us quickly cover this. So, the correlation given in previous section will be applicable for a single component and if you know the property of the mixed vapour as well as mixed condensate you can directly use those correlations in mixed component also. So, the design of condenser for mixed of the vapour is more difficult task, but it will be easy when you have the right property of the mixture.

So, in that case we should consider total condensation of a multicomponent mixture such as the overhead of a multicomponent distillation because condenser is a primary unit which is available with the distillation. So, total condensation of multicomponent mixture we can obtain considering the feed of multicomponent distillation column from the top.

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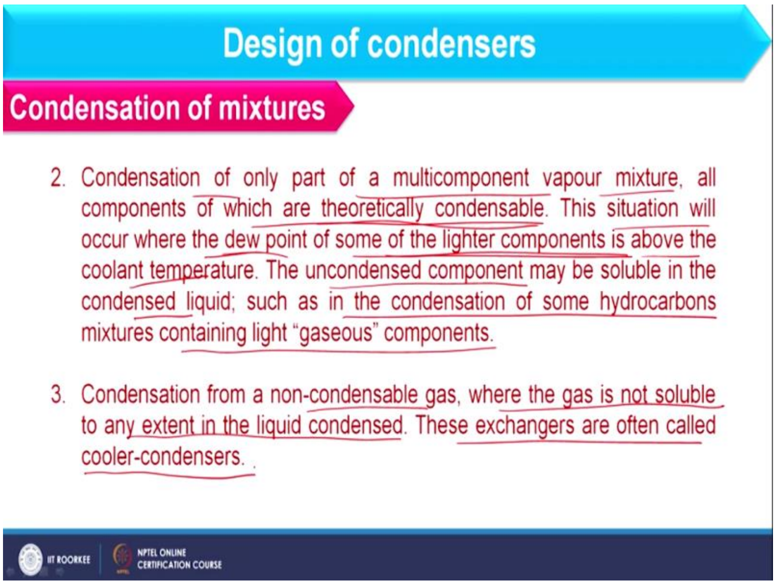

Further, condensation of only part of multicomponent vapour mixture all component of which are theoretically condensable. This situation will occur where the dew point or some of the lighter component is above the coolant temperature. The uncondensed component may be soluble in the condensed liquid such as the condensation of some hydrocarbon mixture containing light gaseous component.

So, in this way you can see the phenomena of multicomponent vapour and how the vapour is soluble in condensed liquid. So condensation from non condensable gases where gas is not soluble in any extent to the liquid condensed these exchangers are often called as cooler condenser. So, in some cases we can consider gases also in condensers.

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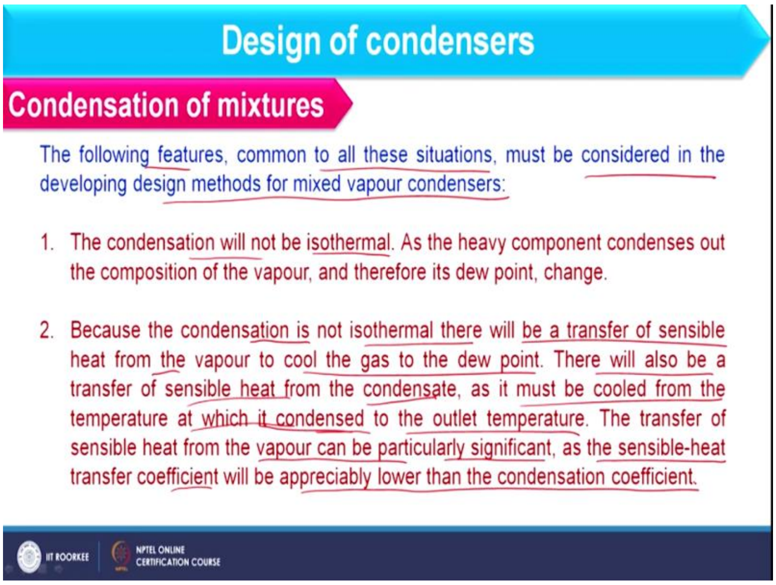

And further we have following features which are common to all these situation and it must be consider in developing design method for mixed vapour condition. So, these points are the condensation the condensation will not be isothermal as I have already told you in mixed vapour condensation is non isothermal and what is the reason that we have already discussed and because of the condensation is non isothermal, there will be a transfer of sensible heat from vapour to cool the gas to a dew temperature.

So, instead of only latent heat transfer we can have transfer of sensible heat also from the vapour to the gases. So, these will also be a transfer of sensible heat from condensate as it must be cooled from temperature at which it condensed to the outlet temperature. So, the transfer of sensible heat from vapour can be particularly significant as the sensible heat transfer coefficient will be appreciably lower than the condensation coefficient.

So, in this way we should compare the coefficient of condensation as well as sensible heat transfer and obviously the condensation coefficient is much higher than the sensible heat transfer coefficient.

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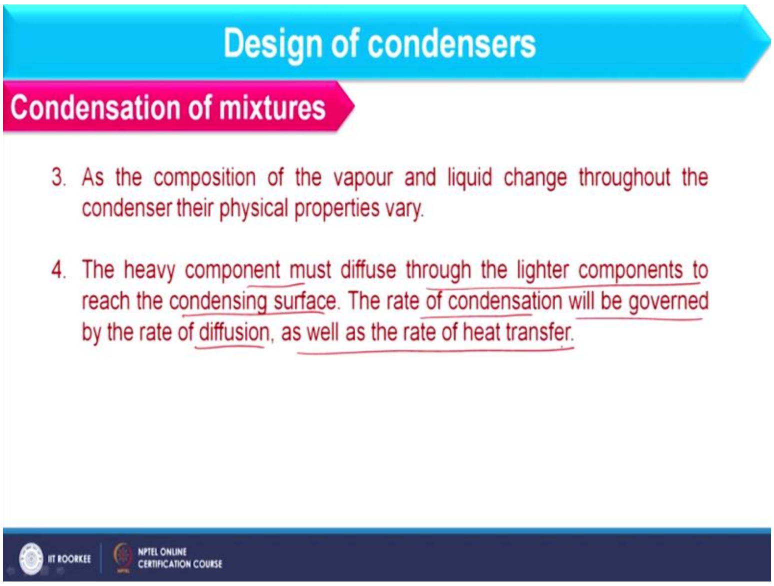

So, the heavy component must diffuse through the lighter component to reach the condensing surface and the rate of condensation will be governed by rate of diffusion as well as rate of heat transfer. So, these are few points when I am dealing with the mixture instead of pure component.

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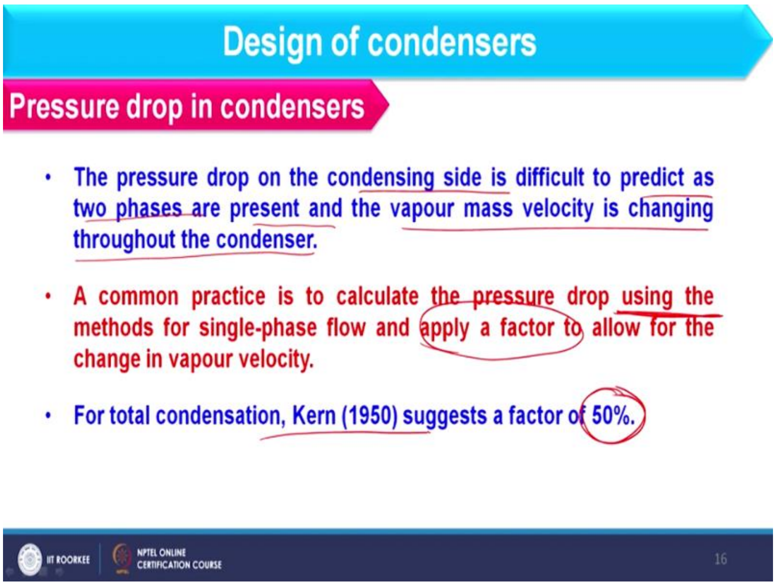

And now lastly we will focus on the pressure drop because this is also an important parameter as far as design of condensers are concerned. So, how I should consider the pressure drop in condenser. In condenser, what will happen vapour will enter, but as condensation proceeds the amount of vapour which is available it will keep on decreasing and amount of condensate will keep on increasing.

So, in this way continuously flow rate of the vapour is changing which is very difficult to count as far as pressure drop calculation is concerned. So, the pressure drop on the condensing side is difficult to predict as two phase are present and vapour mass velocity is changing throughout the condenser. To account this nonlinearity we apply some factors to find out the actual pressure drop in condenser side.

So the usual factor is 50% which is suggested by Kern and this is applicable for total condensation. In this course, I am not focusing on partial condensation and whatever pressure drop you will obtain in condensation side just consider half of that as the pressure drop in condenser and for second side where coolant is available whatever pressure drop you will obtain you consider that as it is. So, here I am winding up the design of condenser.

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And you can have some references to go through about the topic in detail.

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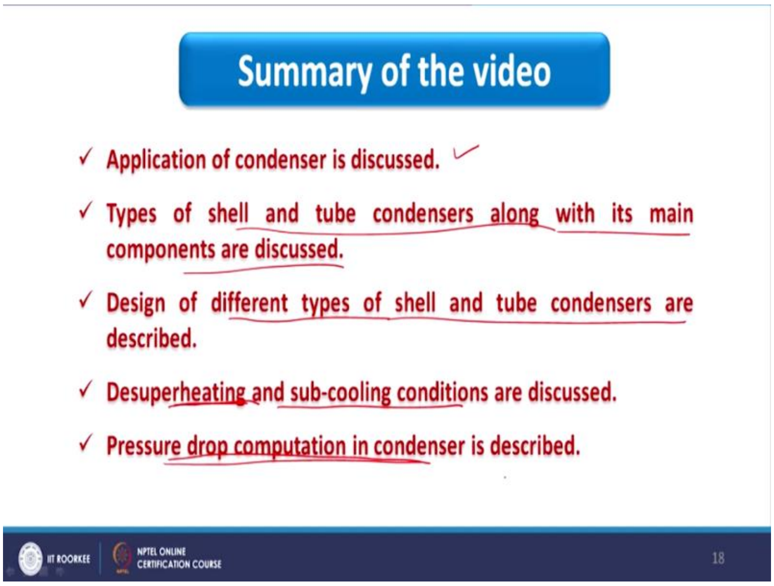

And here I am summarizing the video and this summary is of 22nd video, 23rd video and this video also as in these three video I have covered the topic design of condenser. So, let us see the summary of these lectures. In these lecture, we have discussed application of condenser, types of shell and tube condensers along with its main component and we also describe design of different types of shell and tube condenser depending upon the heat transfer coefficient as well as pressure drop.

Further, we have discussed desuperheating and sub cooling condition in condensers and finally pressure drop computation in condenser is described. So, that is all for now. Thank you.