Process Equipment Design
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Lecture –17
STE Design- Bell's Method-1

Hello everyone. Welcome to the 4th week and here we have lecture 2 of this week and this is overall 17th lecture of the course Process Equipment Design. In this lecture, we will start design of shell and tube heat exchanger using Bell's method. If you remember last lectures we have discussed Kern's method and here we are considering Bell's method. So before starting this design we will first see that when this method is developed.

And what are the conditions in which this method is applicable. Now, if you remember the Kern's method. Kern's method only consider the flow area which is available at the bundle equator that is the maximum possible flow area for any stream in a heat exchanger. So, Kern's consider only that part. However, Bell's method is in more detail where different other factors are also considered.

So, we can say this is the detail design in comparison to Kern's method. However basis is the Kern's method therefore we have discussed Kern's method first and over that we are discussing this Bell's method. So this design that is design of shell and tube heat exchanger using Bell's method I am going to cover in three lectures 17, 18 and 19. So let us start the design of shell and tube heat exchanger using Bell's method.

So, first we will see that where this method is developed. So, Bell's method we consider to calculate shell side heat transfer coefficient and pressure drop. So, this method considers different parameters in comparison to Kern's method.

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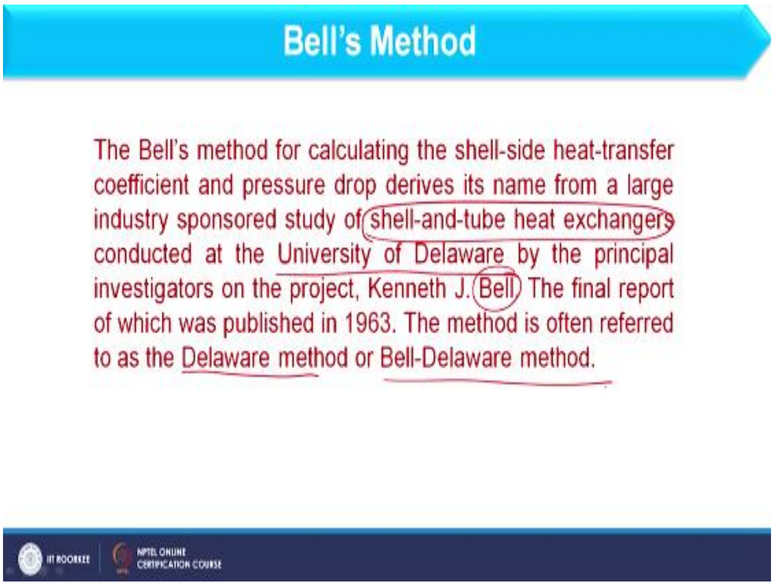

So, this method is developed in University of Delaware by the principal investigator of the project and the project was on design of shell and tube heat exchanger which is the industrial sponsor project and principal investigator of this course was Kenneth J Bell. So based on that Bell's the method name has come. So in some literature you may find some other names also of this method and which we can consider as Delaware method or Bell Delaware method because it is developed in Delaware University.

And Bell has given this method and this method is published in 1963, but method is so detailed that it is used to design shell and tube heat exchanger in current scenario also.

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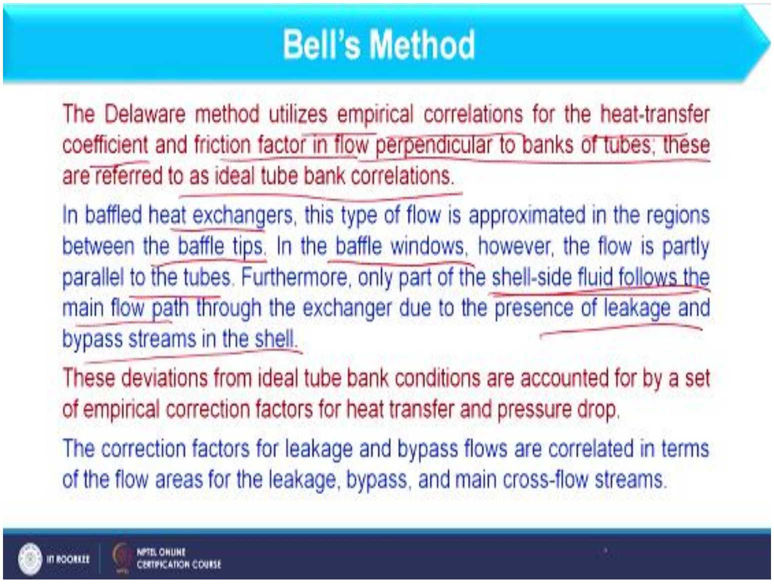

So as far as Bell's method is concerned this method utilizes empirical correlations for heat transfer coefficient and friction factor in flow perpendicular to banks of tubes. These are referred to as ideal tube bank correlation. So, the Bell's method first consider ideal tube bank. It means no hurdle or no effect of other factors are there. So, first of all ideal tube bank should be considered and then we will consider different factors which are corresponding to different conditions in heat exchanger.

Further, in baffled heat exchanger this type of flow is approximated in the region between baffle tip. Which type of flow? The flow perpendicular to the tubes. So, when I am considering the shell and tube heat exchanger this section where it is perpendicular to the tubes it is falling in cross flow zone. So that region is between baffled tip. So, if I consider shell and tube heat exchanger and the shell side here I am having the baffle like this and like this.

So if you see the cross flow zone where the flow is perpendicular to the tubes are this region only. So that is within the baffle tips this is one tip, this is another tip so between the baffle tips we can consider the cross flow zone. In the baffle window, now what is window? Window is basically this section which is between baffled tip and shell inside diameter. So, in baffle windows however the flow is partially parallel to the tube because when I am considering movement it is like this.

So, here it is completely cross and here it is parallel to the flow which is available in tube. Furthermore, only part of the shell side fluid follows the main flow path through the exchanger due to presence of leakage and bypass streams in the exchanger. So, if you consider the shell side many streams are causing leakages and bypasses which will not participate in heat transfer and unnecessary it will create the pressure drop.

So, all these factors are counted in Bell's method. So the deviation from the ideal tube bank which we have just discussed that leakage and bypass etcetera are accounted by a set of empirical correlation factors for heat transfer as well as pressure drop. So, Bell's method basically gives all empirical correlations which affect the ideal tube bank in shell side. It means Bell's method considers the correlation for leakages bypass and main cross flow streams. So you should understand that is in more detail in comparison to Kern's method.

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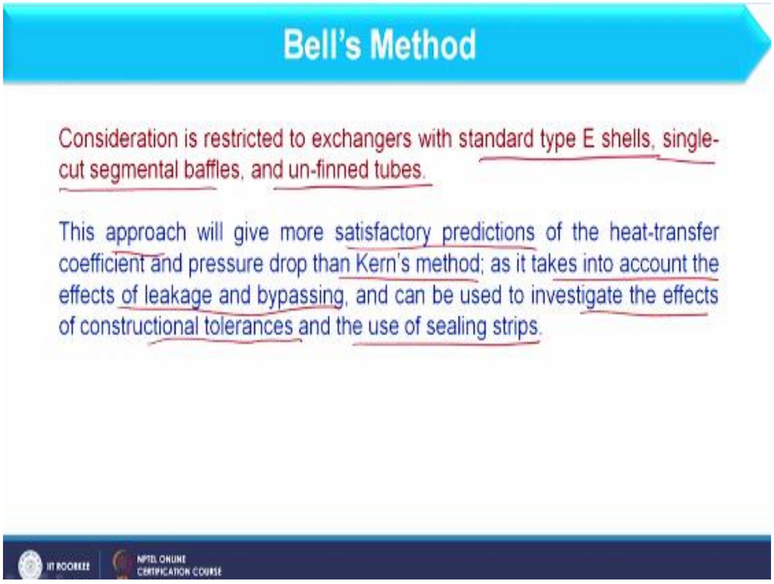

And as far as Bell's method is concerned in this case we consider E shell that is the simplest type of shell. E shell I hope you remember we have discussed all shell arrangement in the topic where shell is discussed in detail that is before Kern's method design that you can see. So, here we are considering E shell single segmental baffle where only one cut is available at the bottom.

And un-finned tubes means tubes are bare it is not having any fin. So, for all these condition we can consider Bell's method and you can also consider these as limitations of Bell's method also. So, Bell's method gives more satisfactory predictions of heat transfer coefficient and pressure drop in comparison to Kern's method because it considers the effects of leakages and bypassing.

And can be used to investigate the effects of constructional tolerance and use of sealing strips. What is these sealing strips and where these are used I will explain that in subsequent lecture. So at present you please consider this as it is and further there is another limitation that if bypass stream. What is bypass stream, what is bypass flow area that will be covered in next slide.

So, if bypass flow area is more than 30% of cross flow area we should use sealing strips until and unless Bell's method will not give correct values.

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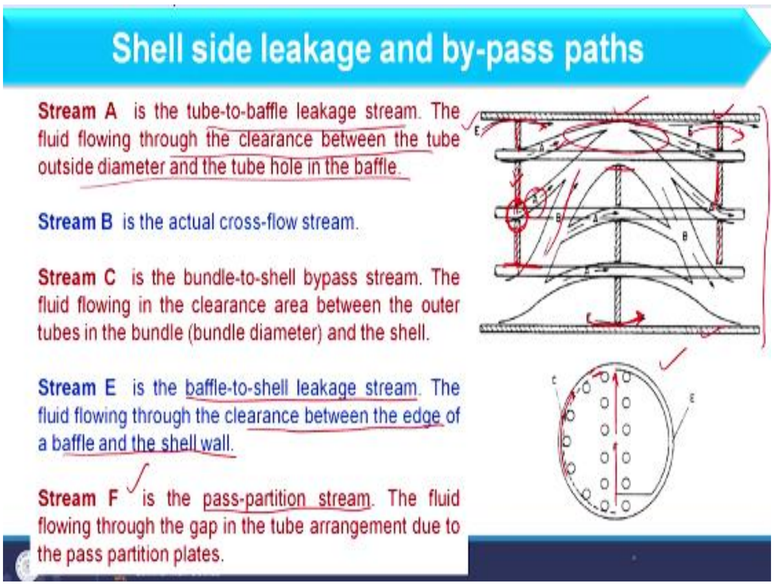

So, here we will discuss shell side leakage and bypass paths. So what are the different streams which are related to shell side that we are going to discuss now. Now, if you see this is the schematic where this is shell and these sections are basically baffles and we have different streams like E, A, B like that and other streams also which are not showing over here that I will discuss.

So, first of all we will focus on stream A which is this. Now where this A stream is available? A stream is available in the gap between the holes which are available in baffle and shell OD and tube OD. So that is basically the gap between hole which is made in baffle and tube OD obviously and this is very obvious also as we have to insert the baffle in tubes. So, insertion is possible when I am having larger hole diameter in comparison to OD of the tube then only it will slide over the tubes.

So that gap basically give stream E which will not participate much in heat transfer, but it will give the pressure drop. So, stream A is the tube to baffle leakage stream which we have just discussed. The fluid flowing through this clearance between tube outside diameter and tube hole in the baffle so that part we have already discussed. Now, next stream is stream B. Stream B is wherever the flow is perpendicular in shell side in comparison to tube side flow.

So this B stream is available basically between baffle tips. So this we consider as cross flow stream. Now, if you remember the Kern's method, Kern's method considers the maximum flow area which is available at bundle equator. So, you can understand that Kern's method only addresses stream B, but only at the center of exchanger not in hole cross flow area which is between two baffle tips.

So, Kern's method consider this stream B with a limitation. So that is stream B now we can have stream C. So, stream C is basically between bundle diameter and shell I hope you understand the meaning of bundle diameter? Bundle diameter means the outer periphery of the tube. The periphery according to the outermost tube which is available in the bundle that and the gap between shell and that bundle diameter we consider that clearance as baffle to shell bypass stream.

In the last slide, we have discuss that Bell's method considers leakages and bypasses. So that bypass is nothing, but stream C. Now, if you consider in this image where this stream C will lie, this stream C will lie in this section or you can clearly visualize this which is available in this schematic that is between shell diameter and bundle diameter. So as this gap increases what will happen over there liquid remain there stagnant.

Liquid will be available there and it will not move. So that zone basically works as dead zone where whatever stream is available it is not participating in heat transfer. So, we should avoid that zone and we have to bring that liquid which is available in bypass between shell dia and bundle dia that stream should bring to the cross flow area and what we have to do to bring the stream to cross flow area that we will discuss in bypass effect.

So here we have stream C. Next, we have stream E. Stream E is basically baffle to shell leakage stream which is clearly shown over here that you can see here I am having stream E and here I am having stream E so that is the gap between shell dia and baffle dia. So the fluid flowing through clearance between edges of the baffle and shell wall. Now, if you consider stream E wherever this stream is available there I am not having a single tube because that is between shell dia and baffle.

So, whatever fluid is available in that gap it is not participating in heat transfer. However, it will create sufficient pressure drop. So, we should also consider that effect in design of shell and tube heat exchanger and then we will have stream F you can consider here in this schematic here I am having the stream F and this is basically the pass partition stream.

Now, if you consider the partition plate in tube side corresponding to that plate whatever region is available in shell side because what I have told you partition plate divides the number of tubes. However, no tube is occurring in the alignment with the pass partition plate. So, whatever region is available corresponding to pass partition plate in shell it will also work as a dead zone may that is available at middle section also, but it will not participate in heat transfer it will remain stay there. So, that is stream F which is due to pass partition plate.

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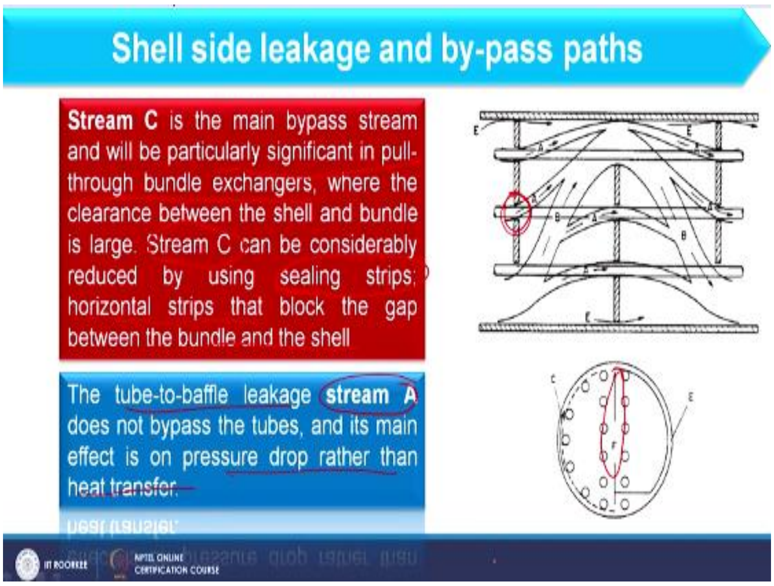

So, if you see when I am considering stream C this is only the bypass stream which is available in shell side and that stream is more significant when I am considering pull through bundle exchanger or internal floating head as we have discussed in lecture which is on classification of heat exchangers there we have discussed that main limitation of internal floating head heat exchanger it is having more shell diameter it means it has more clearance.

So, it has more chance for liquid to remain in bypass section and will not participate in heat transfer. So, we have to bring that fluid to cross flow section and that we will do using sealing strips. So, sealing strips are basically used to reduce the effect of stream C and these are horizontal strips that block the gap between bundle and the shell. So, when we will discuss the effect of bypass stream there we will discuss the sealing strips and its uses how it is placed in detail.

So that is about stream C and further we can see that tube to bundle leakage that is stream A does not bypass the tube because this stream I am considering it is not bypassing the tube and its main effect is on pressure drop rather than heat transfer because it is moving through a minor gap between baffle hole and tube OD. So, these are different streams which are available in shell side and Bell's method considers all these streams except one.

And that stream which is not considered in Bell's method is stream F otherwise it considers all different factors, all different streams than F.

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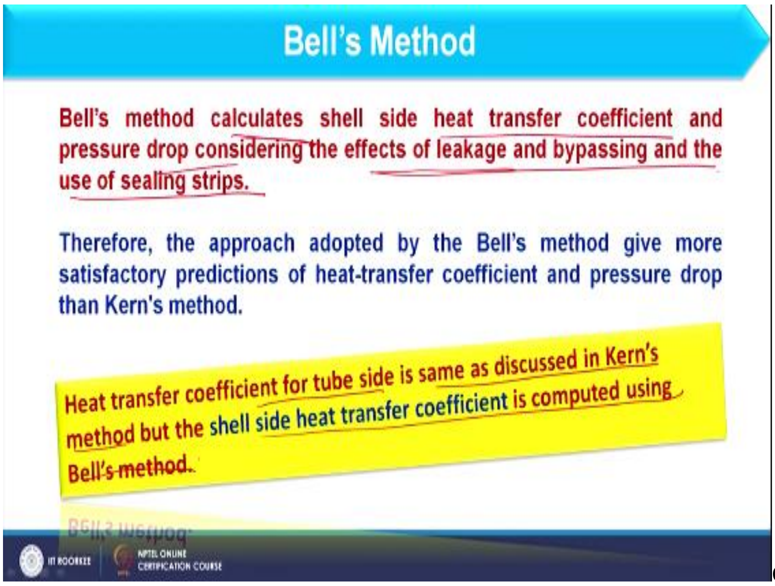

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So, let us start the Bell's method. So Bell's method calculates shell side heat transfer coefficient and pressure drop considering effects of leakage and bypassing and the use of sealing strips. So we will discuss all these factor in Bell's method how it will be applicable. So, if I am comparing this method with the Kern's method obviously Bell's method gives more satisfactory result in comparison to Kern's method.

But it takes more time in designing of shell and tube heat exchanger, but if we require more accurate we should choose Bell's method. So, in that case heat transfer coefficient for tube side is same as discussed in Kern's method, but the shell side coefficient is computed using Bell's method. Actually, there is no method for tube side if I am saying that Kern's method and in Bell's method all these methods are corresponding to shell side calculations only.

Tube side whatever we have discussed till now the same will be applicable for Bell's method also. So based on these streams these leakages and bypasses let us start the design of shell and tube heat exchanger considering Bell's method and in this case first of all we will focus on heat transfer coefficient. So, in this case what is the main criteria and what is the main condition so that heat transfer coefficient of shell side can be obtained.

So heat the main point is initially we consider that tube bank is ideal. What is the meaning of this? It means that we are considering tube which does not have affect of any other factor. We consider tube bank which is not having any effect of other factors to give an example let us say one tube is there, another tube is there. So, what I am saying that this Kern's method initially considers shell side coefficient on ideal tube bank.

It means whatever heat transfer is occurring on this and whatever is occurring on this it is not affecting each other and then we consider heat transfer coefficient as when I am having OD of the tube if you remember the Kern's method we have discussed equivalent diameter to calculate heat transfer coefficient and pressure drop, but here I am not considering equivalent diameter because I am finding that heat transfer is occurring over the tube that is outer surface of the tube and other effects are not there so this gap is also not there.

This is the ideal tube where heat transfer is occurring over this surface. So, therefore we will first consider h oc.

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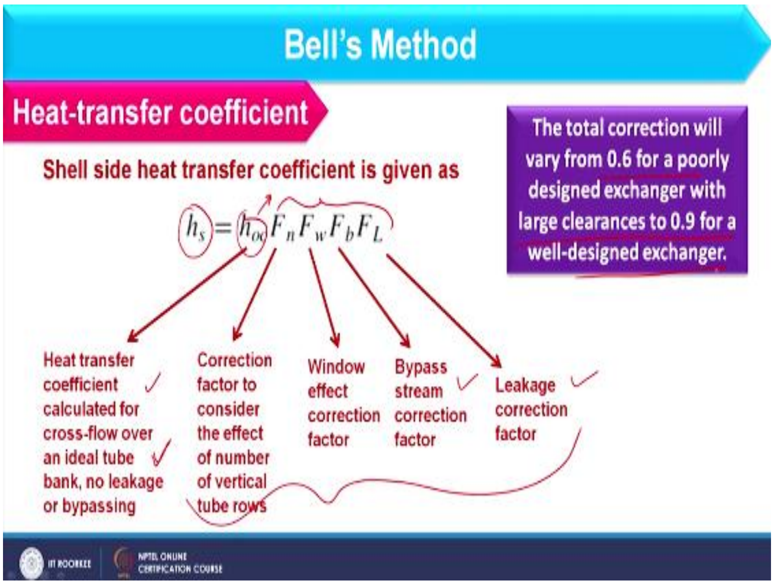

Here in this expression you can see here I am having shell side heat transfer coefficient, here I am having h oc and then we consider different factors. So, let us see what these are? H oc is basically heat transfer coefficient calculated for cross flow over an ideal tube bank where no leakage and bypassing are there. So, once I am calculating h oc after that we will consider different factors such as F n.

So F n is basically the correction factor to consider the effect of number of vertical tube rows. So what basically F n counts? F n counts the vertical tube rows in cross flow zone. So, in detail we will discuss what this F n is and how the value of it will be calculated, but here you should keep in mind that it is for cross flow zone and F w is the window effect correction factor whatever region is available between baffle tip and shell side.

So that effect we consider as F w and further we have F b which considers bypass stream correction factor and finally we have F L which consider leakage correction factors. So, you see all effects we can consider in Bell's method except stream F it is not counting stream F. So total corrections means multiplication of F n to F L will vary from 0.6 for a poorly design exchanger with large clearance to 0.9 for well designed exchanger.

So, in this way we have to consider all factors along with h oc. So, let us start the calculation of h oc that is ideal cross flow coefficient.

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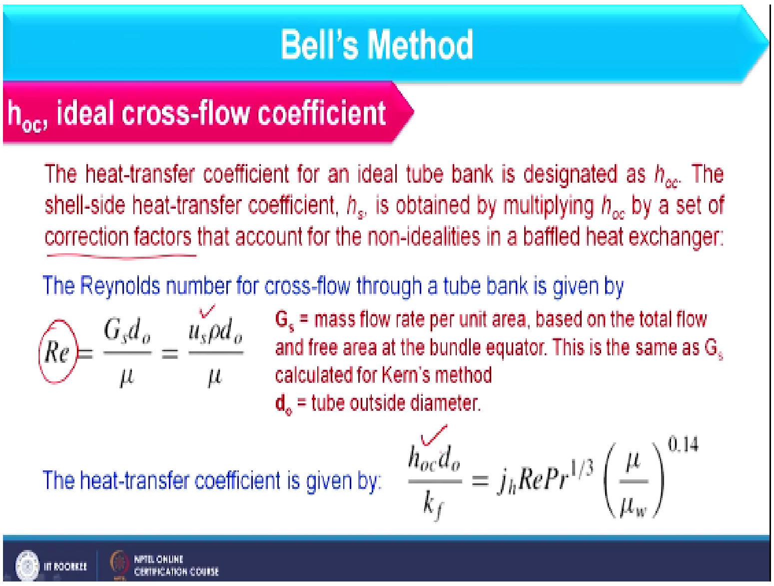

So, the heat transfer coefficient of an ideal tube bank is designed as h oc. The shell side heat transfer coefficient h s is obtained by multiplying h oc by different correction factors to consider non idealities in baffled heat exchanger or the shell side of heat exchanger. For that we have to calculate Reynolds number for cross flow through a tube bank and Reynolds number is basically the function of shell side velocity density d o and mu.

So, here you should consider d o instead of d e equivalent dia we do not have to consider here. So G s is the mass flow rate per unit area based on total flow and free area at bundle equator and this is same as G s you have calculated in Kern's method considering A s and d 0 is outer diameter of tube. So, considering Reynolds number we can find out heat transfer coefficient in shell side.

And that we consider as h oc this is the expression where j h factor you can find from this graph according to the Reynolds number and then you can find out h oc from here. So, in this way we consider ideal cross flow coefficient and then we will multiply this with different correction factors.

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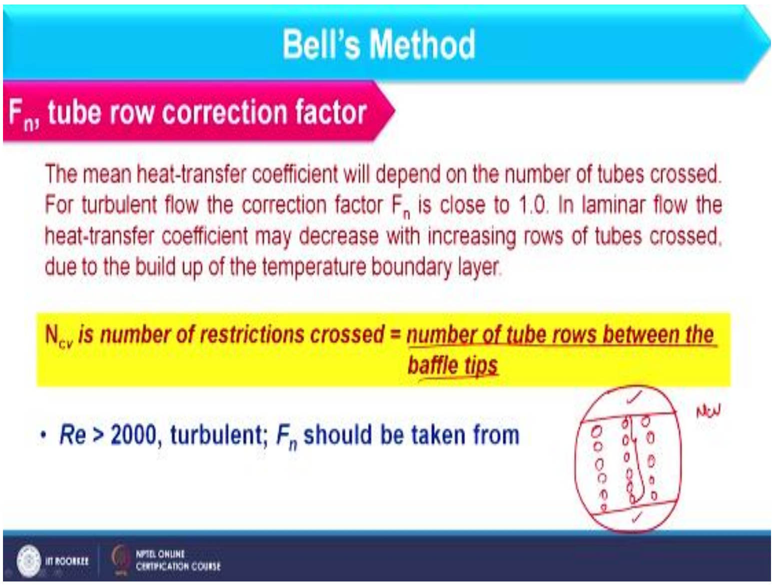

So, first of all I am considering tube row correction factor and that I am representing as F n and in the book same nomenclature is used. So the main heat transfer coefficient will depend on number of tubes crossed means what when the flow is occurring in tube side shell side flow should be perpendicular to that. So, whatever number of tubes are available fluid should pass that tubes and that tube we consider as tube row.

So for turbulent flow factor F n is close to 1 in laminar flow heat transfer coefficient may decrease with increasing rows of tubes crossed due to build up of temperature boundary layer. So these are some points about F n correction factor now we will see that how this factor can be obtained. It will depend on the Reynolds number so if Reynolds number is more than 2,000 we consider that as turbulent region in shell side.

So in that case F n should be taken from this curve. So in that case F n can be computed from this curve where first of all you have to find out N cv and so you can calculate F n so what is

N cv? N cv is basically number of restriction crossed that is the number of tube rows between baffle tips. Now what is this basically? When I am considering cross sectional area of shell and this is basically baffle.

If I consider two baffles it will look like this. This is one baffle and this is another baffle having cut here and here. Now number of tube row between baffle tips. So, these are basically the baffle tips and if I am having tube rows like this. So in this way we can consider these as N cv and so the N cv is basically the number of tube rows crossed by fluid when it is available between two baffle tips. So N cv is basically number of tube rows between two baffle tips.

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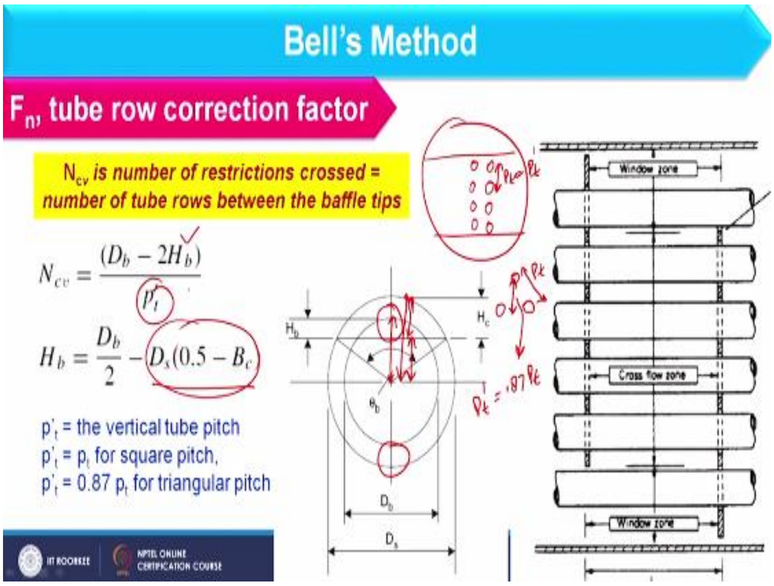

So first of all we have to find how to compute N cv and so we can calculate F n that is tube row correction factor. To understand that, we consider this schematic where number of tube rows are basically these so that is available between two baffle tip one tip is this, one tip is this and here we have this window zone and in between baffle tip we consider cross flow zone.

So, let us start how to find N cv. So N cv if you see the expression that is basically D b – 2 H b / P t dash and what is this D b and H b that we can explain through this schematic here if you see this is the shell dia and here I am having bundle dia. So, bundle dia obviously lesser than the shell dia and what is this if I consider this section what is this? This is basically baffle cut and this code is making angle theta b at the center.

So H b is what? H b is basically the section of bundle which is available in window zone this will be the window zone. So H b is basically this length of diameter which is beyond baffle cut. So, if I consider N cv so N cv should be what baffle diameter plus twice of H b because if I consider second cut it will be like this. So between this and this whatever tube rows will be available that is nothing but N vc.

So, here I am considering this also as H b and this is also H b. So between these two we have to find out N cv value using this expression. So, first of all let us see how I can calculate H b or you can simply apply geometry over here you can find the H b value on your own, but let us discuss that so that should be D b / 2. So, D b / 2 means this and minus D s D s is what? Shell dia bracket 0.5 means half of shell dia like this minus B c.

So B c is what? B c is this factor. So, what is this 0.5 – B c into D s that is basically this section and if I am removing this section from bundle diameter I can find H b value and H b value twice I have to use because N cv should be obtained between two baffle tips. So, in this way you can find out N cv and here another parameter is there that P t dash. Now what is this P t dash?

P dash is basically distance between two tube rows if I am considering cross sectional view of shell like this and if tubes are available like this. So is it possible to have triangular pitch as well as the square pitch. If square pitch is there this will be equal to P t and that will be equal to P t dash as well. Now, if I am considering triangular pitch like this. So, P t is this, but this distance is slightly lesser than P t so it would be 0.87 into P t which is equal to P t dash.

So that is the gap between two tube rows. So N cv we can consider by this expression that is D b – 2 H b / P t dash and that N cv should be complete number if it comes as decimal you have to round it up not round off.

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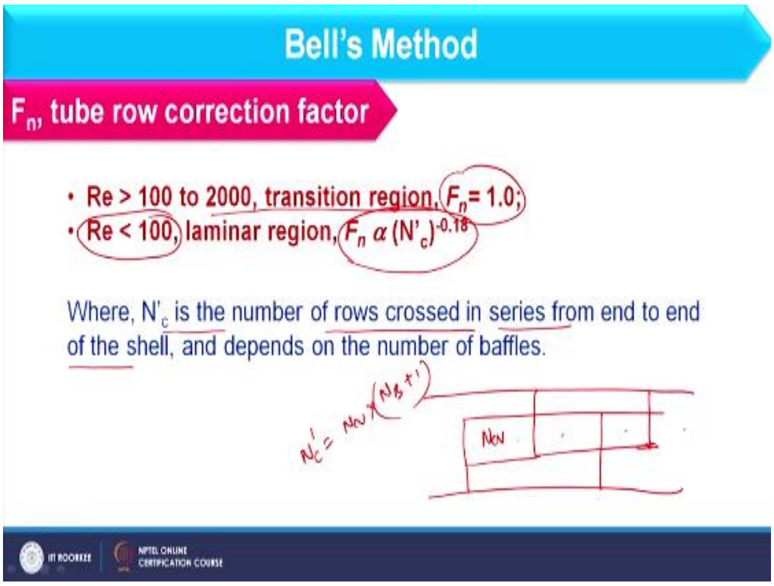

So in that way we can find out the N cv and so in that way we can find N cv value and you can refer the previous gap to find out F n value, but that will be applicable when Reynolds number is more than 2,000. Now what will happen when Reynolds number is 100 to 2,000 that we consider as transition region in shell side in that case F n should be taken as 1 you do not have to do anything.

And further if it is falling in laminar zone where Reynolds number is less than 100 we have to use this expression where F n is the function of N c dash power – 0.18. Now what is this N c dash? N c dash is basically number of rows crossed in series from end to end of the shell like if you are having the shell here I am having the baffles like this. So, between baffle tips here I am having N cv so N c dash will be N cv into number of these gaps.

So that will be number of baffle plus 1. So in that way we can find out N c dash and you can find out F n for laminar zone. I hope things are clear to you it will be more clear when we will illustrate the design of shell and tube heat exchanger with the help of example based on Bell's method and I will continue this design in next lecture also. So, that is all for now. Thank you.