Process Equipment Design
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Lecture –19
STE Design- Bell's Method-3

Hello everyone. Welcome to the 4th lecture of week 4 of the course Process Equipment Design and this is the 19th lecture of this course. Here we are going to discuss design of shell and tube heat exchanger using Bell's method. So, if you remember the design of shell and tube heat exchanger using Bell's method we have started in second lecture of this week and in this lecture we will cover the last part of the design.

So, in second and third lecture we have discussed design using Bell's method and in these two lectures we have covered the calculation of heat transfer coefficient in shell side. In this particular lecture, we will cover pressure drop calculation in shell side when Bell's method is applied. So, let us start this lecture. Now as far as Bell's method is concerned, it is applicable only in shell side.

And when I am considering the pressure drop in shell side it has basically two reason. One is when I am having the cross flow and second reason when I am having window zone.

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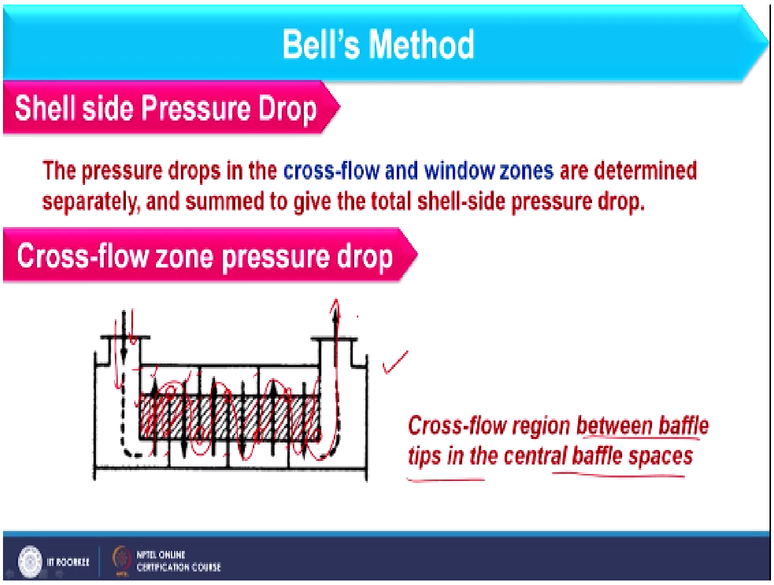

So, the pressure drops will be calculated in these two regions individually and then according to the number of these regions we will add pressure drop and then we will find out total shell side pressure drop. So, first of all we will focus on cross flow zone and we will discuss empirical correlations to find out pressure drop in cross flow zone, but first we should understand that what is cross flow.

Now as we are already discussing the Bell's method from last two lectures you must be aware about cross flow zone and the window zone. So, cross flow zone is basically that zone which is falling between two baffle tips, between two consecutive baffle tips. So, if you see this schematic here cross flow region is shown between baffle tips in central baffle spaces. So, when I am saying that fluid is entering into the shell.

So from this side it is entering and then it is moving between two baffle tips like this and like this and if I am speaking about baffle tip one tip is this second tip is this and similarly we have other tips. So, between two consecutive tips whatever space is there which is also shown over here through shading. So, here between two baffle tips whatever flow area is falling that we consider as cross flow zone.

Now, if I ask you that how many cross flow zone will be there? So if you see here we have this cross flow so 1, 2, 3, 4, 5, 6. So, total 6 cross flow zones are there. Now, if I count the number of baffles these are basically 1, 2, 3, 4, 5, 6, 7 so number of cross flow zone is basically equal to number of baffle – 1. So, we will first find out the pressure drop between two baffle zone or we can say in one cross flow zone.

And then we will consider that in different cross flow zone from one end to another end of the shell. So when the fluid is entering into this it is basically moving through the cross flow zone like this and finally it exits from this side.

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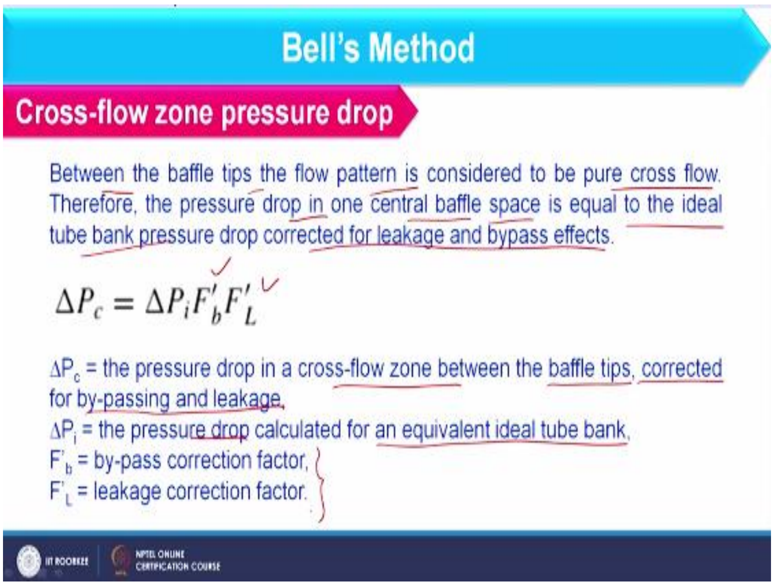

So, let us see the cross flow zone pressure drop how we should obtain that. So, what should be the pattern in cross flow zone pressure drop? We can understand that between the baffle tips the flow pattern is considered to be pure cross flow. Why it is cross flow because in tubes fluid is moving horizontally and when shell side fluid will come between two baffle tip it basically moves perpendicular to the tubes and therefore it is called as cross flow.

So, when I am considering baffle tips the pattern is pure cross flow and therefore the pressure drop in one central baffle space is equal to the ideal tube bank pressure drop corrected by leakage and bypass effects. So, here again we are considering the ideal tube bank and then we will consider different correction factors as we have studied in heat transfer coefficient of shell side.

So, let us see the expression for the pressure drop in cross flow zone. So, here I am having the pressure drop expression like delta P c = delta P i F b dash and F L dash. So, here we have used bypass correction factor and leakage correction factor and name them differently using prime. So F b prime and F L prime so that should be the bypass and leakage correction factor for pressure drop calculations.

So, if I am asking what is delta P c? It is basically the pressure drop in cross flow zone between baffle tips we have already discussed and that should be corrected by bypass and leakage. Delta P i is the pressure drop calculated for an equivalent ideal tube bank and F b prime and F L prime I have already discussed. Now the point is why we are considering bypass and leakage correction factor.

Why I am not considering F w prime or F n prime like window correction factor and tube row correction factor. The answer is in the cross flow zone we will have leakage in terms of the gap between hole in baffle as well as tube OD and we can also understand that fluid is available in bypass zone and when we will consider sealing strips over there the fluid will return back to the bundle.

And bundle mean between two tips of baffles so it should be in the cross flow zone. So considering these factors we will consider F b prime and F L prime. F w prime we are not considering because it is entirely in different zone and F n prime I am not considering because that I am already accounting in delta P i and that you can see in next slide. So, you see cross flow zone pressure drop only accounts leakage and bypass correction factor. So, let us start with delta P i how we are considering pressure drop on ideal tube bank.

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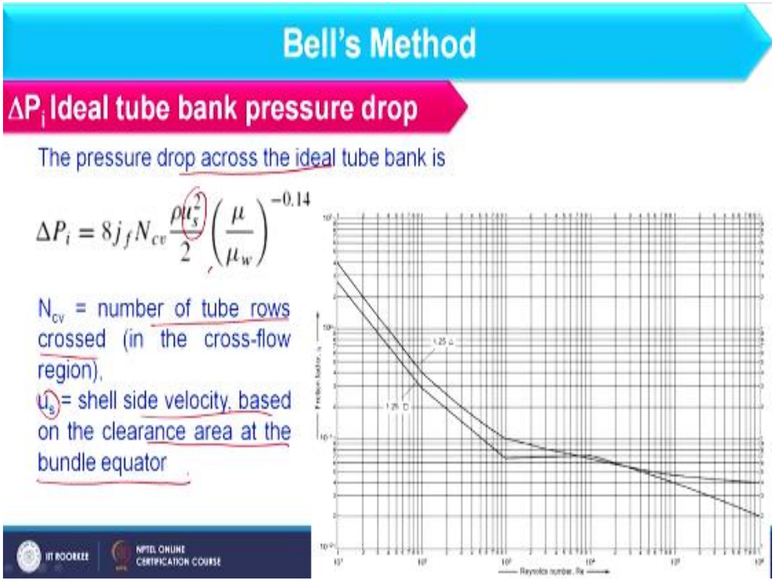

So, here I am having pressure drop across the ideal tube bank and it is given by this expression 8 j f N cv rho u s square / 2 and this is viscosity correction factor. So N cv that you understand this is nothing, but the number of tube rows crossed. So, if I am considering delta P i and in cross flow zone I am not having any longitudinal movement I am only having transverse movement or the movement perpendicular to the tubes.

So, whatever friction we can have that will be due to tube rows how many tube row the fluid is crossing between two baffle tips. Therefore, we are considering N cv in ideal tube bank because here ideal tube bank does not mean that I am having only one row I am having multiple row and because of that I am getting pressure drop when leakages and bypasses are not there.

So, delta P i if I am considering that ideal tube bank it does not mean that I am having only one row that I am repeating also because it is basically between two baffle tips and if tubes are arranged in a definite manner it has to cross all tube rows and therefore I am considering N cv and because I am already considering N cv I am not considering F n dash that is tube row correction factor.

So we are only accounting N cv and how we have to find out N cv value that I have already explained in the previous to previous lecture like lecture 2 of this week and you can go through that lecture to understand N cv and u s if you see u s is basically the shell side velocity based on clearance area at bundle equator. So, as we have considered velocity in Kern's method in the similar line we can use velocity here.

So here I am having pressure drop at ideal tube bank. So, let us consider different correction factor into this.

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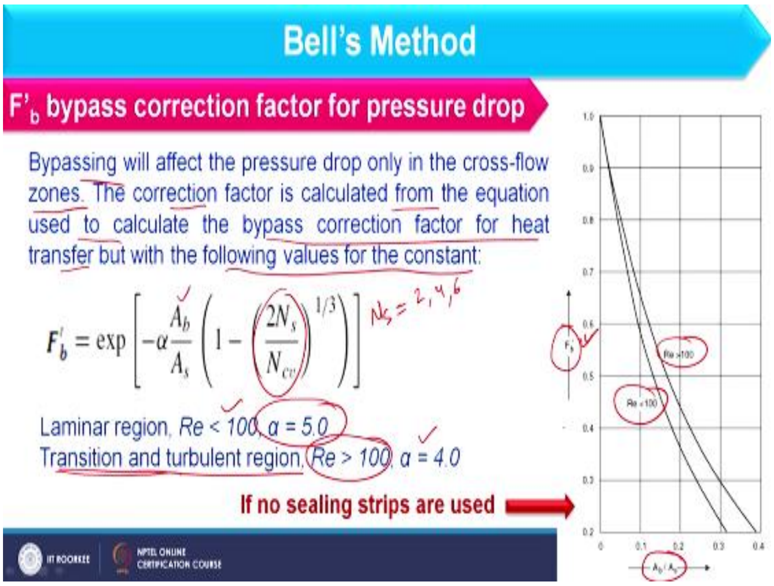

First of all, let me speak about bypass correction factor for pressure drop. So, bypassing will affect the pressure drop only in the cross flow zone. As I have already told you that whatever fluid is available in bypass zone putting sealing strips we bring it to the cross flow zone. Therefore, bypassing effect should be considered in cross flow zone. So, the correction factor for this is calculated from the equation used to calculate bypass correction factor for heat transfer, but with following values of constant.

So if you see if you remember the bypass correction factor equation there I am having one factor that is alpha. Other parameters like A b, A s N s N cv all these value will be same. So the expression is like F b dash – alpha A b / A s and this is the sealing strips and N cv values. So, all these parameters you know and here whatever N s you have fixed in heat transfer coefficient let us say that may be 2 that may be 4 or 6 because these numbers you have already fixed when F b you have obtained more than 0.85 if you remember.

So, whatever sealing strips you have fixed there the same sealing strips you can use here directly. Here again you should not calculate that whether sealing strips are required or not whatever we have fixed the same you can use over here and at the same time N cv we can also fixed as we have fixed in heat transfer coefficient calculation. So the only change will be for alpha value.

If I am having laminar zone that is Reynolds number is less than 100 alpha should be 5.0 and for transition and turbulent region when Reynolds number exceeds 100 alpha value should be equal to 4. So in this way you can find out bypass correction factor for pressure drop calculation. Further, if you have obtained N s = 0 it means no sealing strips are required so that we can already fixed in heat transfer coefficient calculation.

So, if this is the case like no sealing strips are required in that case you can use this graph to find out F b dash value. Though this graph looks like similar as you have considered in heat transfer coefficient calculation when you have used F b, but here you should understand it is F b dash so value must be different. So depending upon A b and A s value you can find out the F b dash value in whatever region the flow is occurring. So in this way you can find out bypass correction factor for pressure drop.

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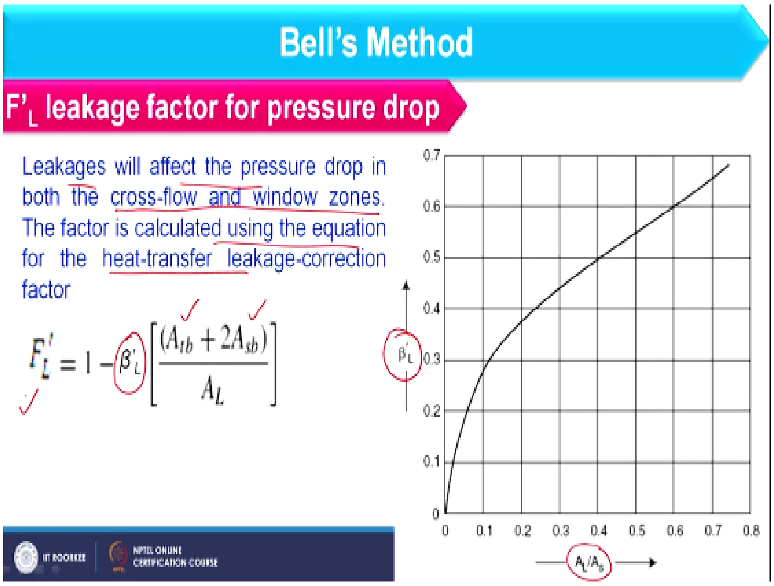

So, further we should understand F L dash that is leakage correction factor for pressure drop. So leakages will affect the pressure drop in both the cross flow as well as window zone because in cross flow zone again we have the leakages between baffle hole and tube OD and in window zone we have leakage between shell dia and baffle dia. So, between that space we can find leakages.

So, leakage correction factor should be applicable to cross flow zone as well as window zone both. So, the factor is calculated using the equation which we have considered in heat transfer calculation and that equation is this equation, but here we have the change in beta L dash value. So, A tb and A sb values as we have obtained in heat transfer coefficient calculation the same you can use over here.

So once you have A L and A s you can find out beta L dash value from this graph and then you can use this equation to find out leakage correction factors. So, the main thing is whatever you have fixed in heat transfer coefficient calculation the same you have to use in pressure drop calculation also with slight modification and the reason is very simple like whatever C s C t or N s you have considered in heat transfer coefficient.

The same will be applicable for pressure drop also because for pressure drop no geometry should be different than that we have considered in heat transfer calculation. So, in that way we can consider leakage correction factor for pressure drop.

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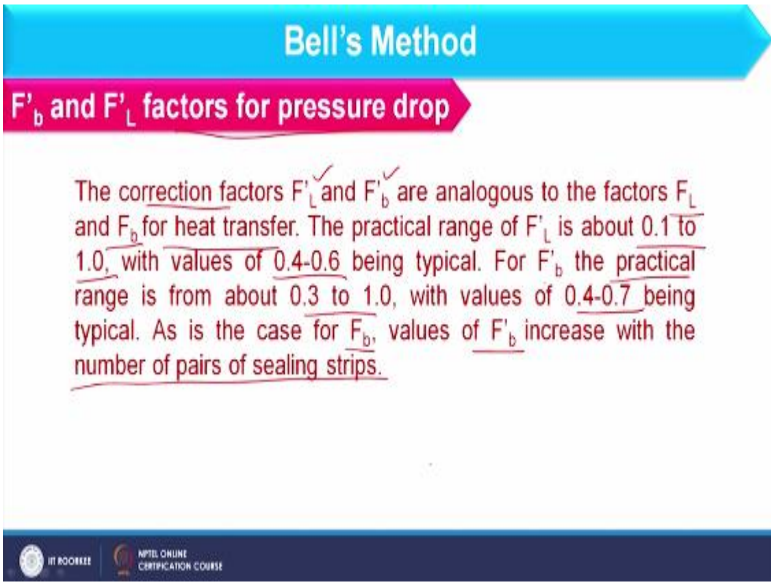

Now here we have F b dash and F L dash factors for pressure drop and here we are going to understand the range of these factors. So, the correction factors that is F L dash and F b dash are analogous to factors F L and F b for heat transfer that we have already discussed. Now the practical range of F L range is about 0.1 to 0.1 with values 0.4 to 0.6 being typical. So, it will be better if value will lie between 0.4 to 0.6.

For F b dash the practical range varies from 0.3 to 0.1 however w can consider value 0.4 to 0.7 as recommended value. So as is the case for F b values of F b dash increase with number of pairs of sealing strips. Therefore, I have already told you that whatever you have fixed in heat transfer coefficient calculation the same sealing strips you have to use over here and you should understand that these sealing strips are even in number because it should be considered in pairs and now we will focus on window zone pressure drop.

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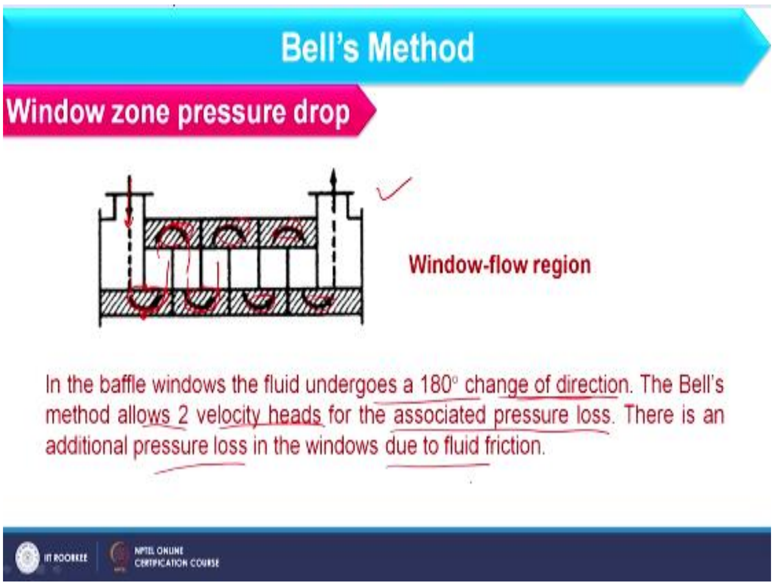

So, first see what is window zone? If you consider this schematic here fluid is entering and we have already considered the section which are falling between baffle tips that we consider as cross flow zone. However, we can consider the zone which is available between baffle tip and shell diameter so that zone basically we can call as window zone as showing in this schematic through shading.

So, here you can count that how many window zones are falling from end to exit nozzle in the shell side. So, in baffle windows the fluid undergoes a 180 degree change in direction because here if you see it is basically like U tube or complete reversal of the flow. So here we have 180 degree change in direction of the flow of the fluid the Bell's method allows two velocity heads for the associated pressure loss when the fluid is moving at 180 degree direction.

There is an additional pressure loss in window due to fluid friction. So in this way we have to consider the pressure drop in window zone and now we will see the empirical correlation to find out pressure drop in window zone and that pressure drop should be corrected by leakage correction factor so F L dash we will further count here.

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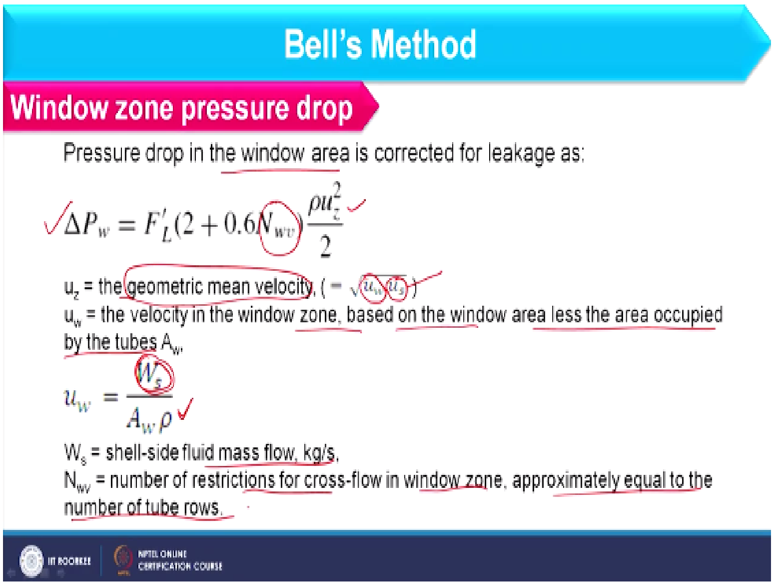

So, when we focus on pressure drop in window area or window zone this is the expression delta P w is equal to F L dash 2 + 0.6 N wv rho u z square / 2. So here as far as u z is concerned this is the geometric mean velocity of which velocities? The velocity which is occurring in cross flow zone and velocity which is occurring in window zone. So, that should be the geometric mean of u w as well as u s that is for cross flow zone that you have already seen in Kern's method.

And u w is basically velocity in window zone based on window area less the area occupied by the tubes. So what is u z? U z will depend on the area which is available for fluid to move in window zone and that you can find out considering window zone area – the area occupied by the tubes in window zone. So, we will see the detail calculation of u w in the next slide and expression is u w is w s that is the shell side fluid flow rate.

A w is basically the area which is available in window zone for free flowing of fluid and row is the density of the fluid which is available in shell side. So here w z you can understand that I have already explained and finally you have to consider N wv because N wv is also required in pressure drop in window zone. So, N wv is basically number of restrictions for cross flow in window zone approximately equal to number of tube rows in window zone.

Now what is N wv? If you remember N cv is the vertical tube row within baffle tips and that we consider as tube rows in cross flow zone. In the similar line we can consider cross flow in window zone because fluid whatever is moving it will cross all the tubes. So it will create sufficient friction when it will cross the tube rows therefore N wv should also be considered over here.

So, how we should find out N wv and how we should find out U z u w that we will discuss in upcoming slide.

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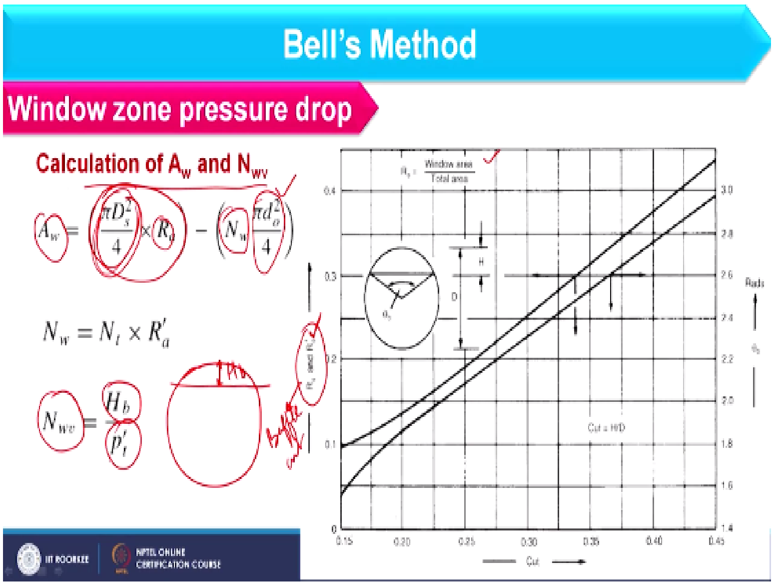

So here we should consider the calculations of A w and N wv. So as far as A w is concerned that is basically what is A w? A w is basically free area which is available for fluid to move in window zone. So how I can consider that? If you see the expressions goes as pi D s square / 4 so that is nothing, but the cross sectional area of shell and what is R a? R a we have already discussed in lecture 2 and lecture 3 of this week.

And this is basically window area by shell area window cross sectional area by shell cross sectional area. So, if I consider this is basically shell cross sectional area and here I am having window zone by shell cross sectional area. So, this will give total window cross sectional area if I am having R a value and I will further deduct the area which is occupied by the tubes.

So, pi D square / 4 is the outer cross sectional area of one tube into N w, N w is basically total number of tubes available in window zone. So N w we can find out by N t into R a dash and R a and R a dash you can find out from this curve only. R a dash you have already obtained to calculate window correction factor in heat transfer coefficient of the same value you can obtain or you can consider.

And here R a is basically window area by total area that we have already discussed. So, R a will depend on baffle cut and R a dash will depend on bundle cut that we have already discussed. So, using this curve you can find out R a and R a dash value and then you can find out A w. Now how I should find out N wv that is the number of tube rows in window zone. So if you consider H b. H b is what?

H b is that section of the bundle which is available in window zone so height of that section if I am having this bundle and let us say your baffle is up to here only so this is basically H b / P t dash and P t dash you understand when I am having square pitch it is equal to P t and when I am having triangular pitch it is 0.87 into P t. So in this way you can find out N wv.

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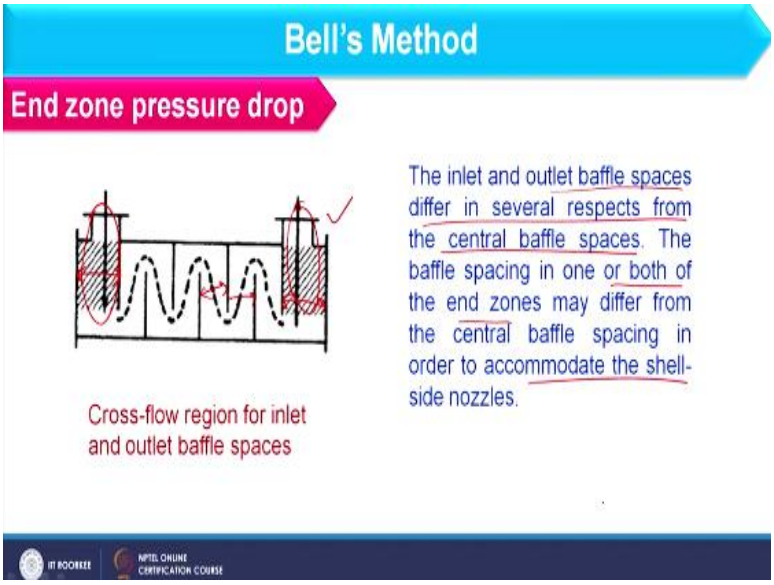

And now we will focus on end zone pressure drop. So, as you can see here we have end zone where fluid is entering and from where fluid is exiting these zones we are considering as end zones. So the inlet and outlet baffle spaces differ in several respects from central baffle spaces like whatever spacing are there in between here spacing will be slightly different as you can observe from this image also.

So, the baffle spacing in one or both the end zone may differ from the central baffle spacing in order to accommodate shell side nozzles. So how we should consider the pressure drop in end zones? When I am considering pressure drop in end zone you should understand that in end zone we have only one baffle window because when the fluid will enter it will come across with the first baffle and below that we have window zone.

So, it is slightly different than whatever we have considered in cross flow zone because in cross flow zone we have two window zone however that is not in the case of end zone and therefore if I am considering total number of tube rows crossed so that should be equal to N cv + N wv because we are having only one window zone.

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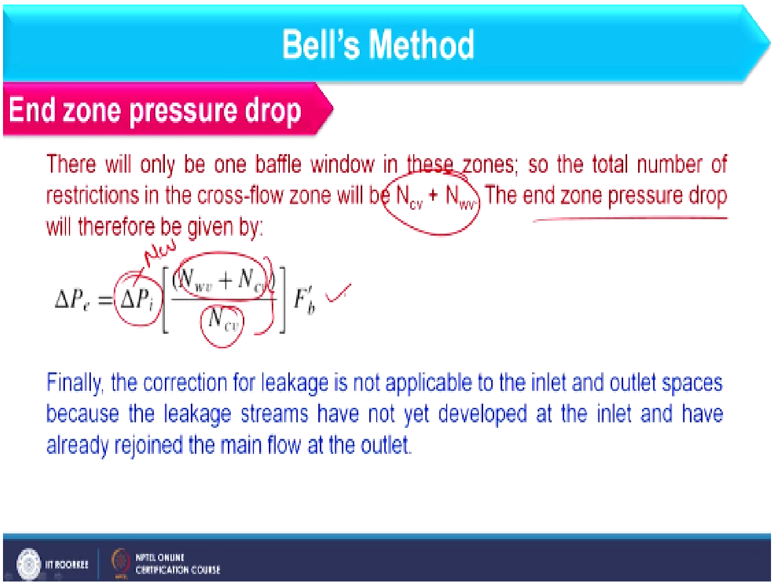

So, total tube rows crossed will be equal to N cv + N wv and therefore we can consider end zone pressure drop as delta P i which is for the cross flow and number of vertical tube rows crossed we can change over here because this contains N cv so we can divide this and then multiplied the required number of tube rows and F b dash that is bypass correction factor will lie over here. So in this way you can find out end zone pressure drops.

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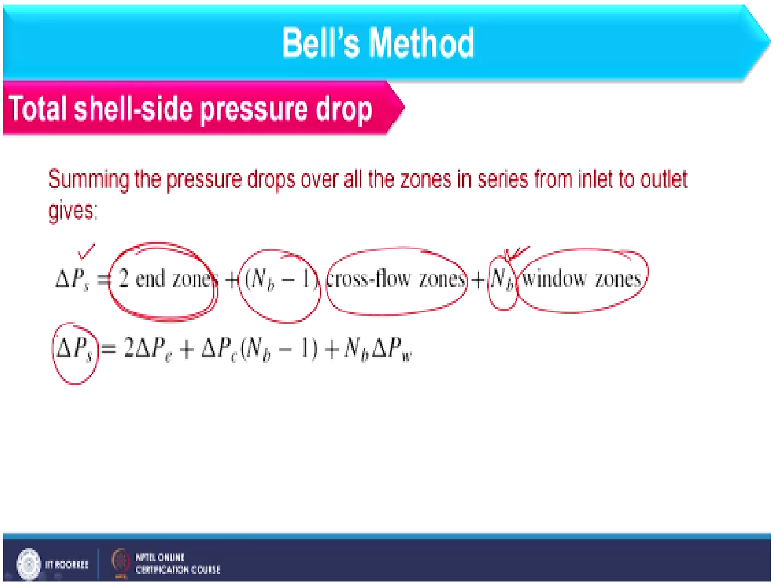

And once you are having the end zone pressure drop, window zone pressure drop and cross flow pressure drop we can consider total pressure drop from end to another end of the shell like this we are having this is delta P s that is pressure drop in total shell and each shell will have two zones at least and each shell will have at least two end zones. How many cross flow zones will be there because if you remember previously we have counted number of baffles as 7 and number of cross flows as 6.

So N b – 1 will be total cross flow zone and N b into window zone that is an N b and total number of window zone will be equal to N b. So, in this way you can find out individual pressure drop and then you can multiply with the respective number to find out total pressure drop in shell side.

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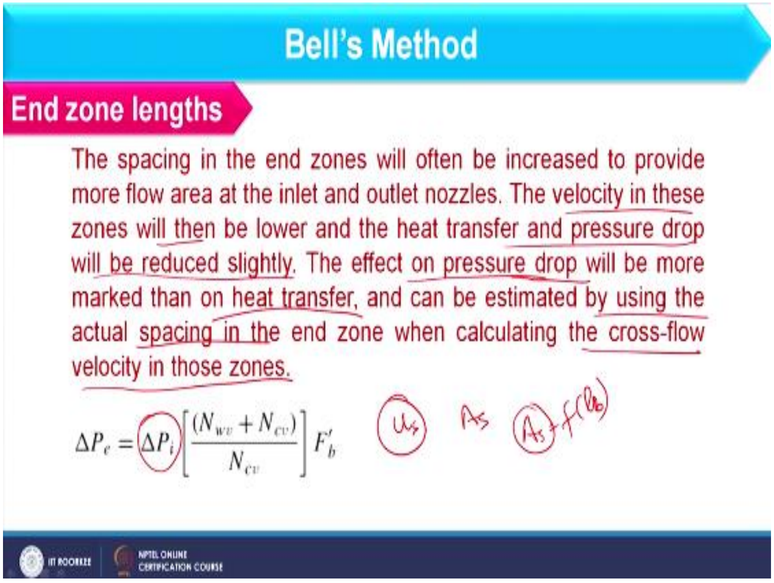

So, here another point you should consider that in end zone spacing is different than that we have consider in cross flow zone between two baffles. So, in this case we should consider pressure drop in slightly different manner and that is velocity in these zones will then be lower than the heat transfer and pressure drop will be reduced slightly. So, when I am considering more spacing in end zone I should have lesser velocity which will give lesser heat transfer coefficient and lesser drop.

And effect of that we can observe more in pressure drop instead of heat transfer and it can be considered by using the actual spacing in end zone when calculating cross flow velocity in those zones. So, if you remember delta P i considers cross flow velocity and that should be u s and u s will depend on A s and A s will depend on baffle spacing. So, if baffle spacing will be more we should consider A s for end zone differently and so the u s.

So, in this case what we can conclude that pressure drop of ideal tube bank you can consider differently in end zone and cross flow zone and that will depend on the baffle spacing in these two zones. So, in this way we should consider pressure drop in baffle spacing and here we have the effect of fouling on pressure drop.

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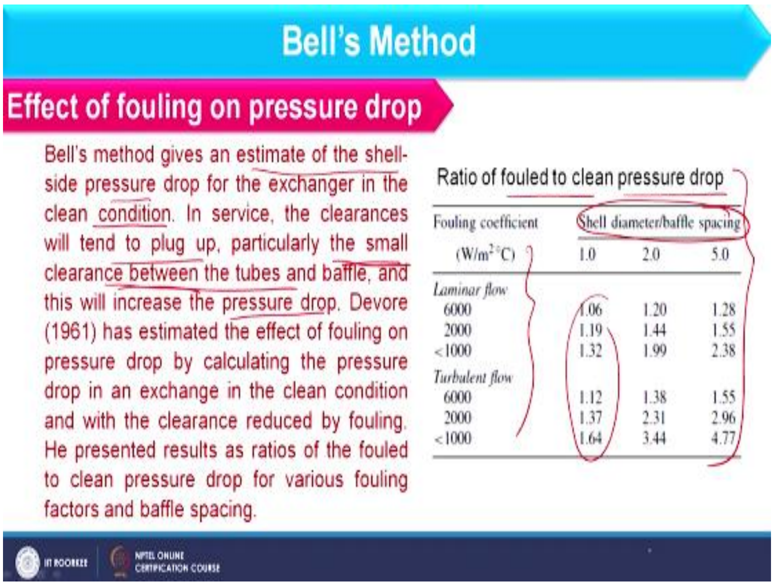

So Bell's method gives an estimate of shell side pressure drop for the exchanger in clean condition. In service the clearance is tend to plug up particularly in small clearance between tubes and baffle and this will increase the pressure drop and therefore we can have one table where ratio of foul to clean pressure drops are shown depending upon the baffle spacing and the regions.

So, in this way we can find out the pressure drop in fouling condition when I have already calculated that for clean condition using Bell's method. So, the design of shell and tube heat exchanger using Bell's method is completed over here.

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And these are some references you can study these steps in detail in these references and here I am summarizing the video and this summary is of lecture number 2, 3 and 4 of this week where I have discussed design of shell and tube heat exchanger using Bell's method.

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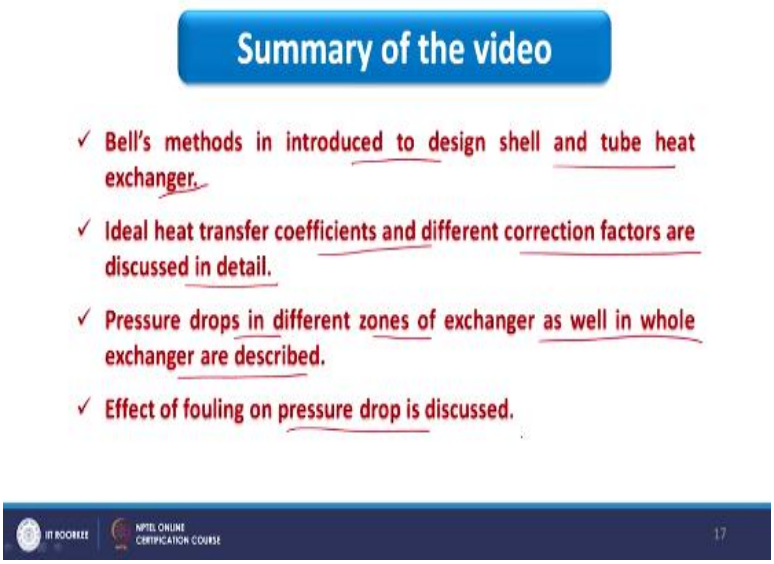

So, summary goes as Bell's method is introduced to design shell and tube heat exchanger. Ideal heat transfer coefficient and different correction actors are discussed in detail. We have also discussed pressure drops in different zones of the exchanger as well as in whole exchanger and lastly we have discussed effect of fouling on pressure drop. So that is all for now. Thank you.