Process Equipment Design
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Lecture –20
STE Design – Bell’s Method Example-4

I welcome you all in this lecture which is lecture number 20 of the course Process Equipment Design and here we are at the end of 4th week of this course and in this lecture we will illustrate design of shell and tube heat exchanger using Bell’s method with the help of one example. In this example, I am going to discuss the Bell’s method in detail with each and every step.

So as far as design of shell and tube heat exchanger using Bell’s method is concerned that I have already covered in 2nd, 3rd and 4th lecture of this week and all those steps will be applied in this example.

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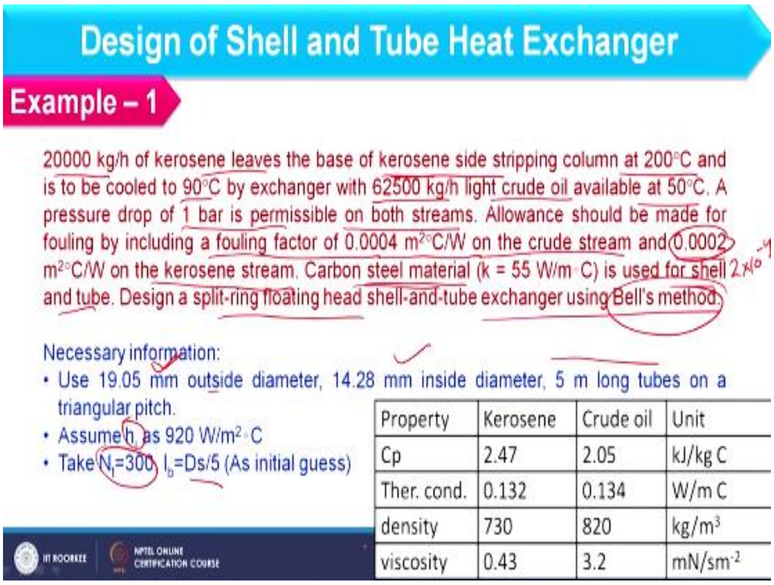

So, let us start this. So, here I am having example 1 and in this example we have 20,000 kg per hour of kerosene which exits the base of kerosene side stripping column at 200 degree Celsius and to be cooled to 90 degree by exchanging heat with 62,500 kg per hour of light crude oil which is available at 50 degree Celsius. A pressure drop of one bar is permissible on both streams.

Allowance should be made for fouling by including fouling factor of 4 into 10 to the power – 4 meter square degree Celsius per watt on crude side and 2 into 10 to the power – 4 meter square degree Celsius per watt on kerosene side. So, carbon steel material is used for shell and tube and here we have split ring floating head shell and tube exchanger and we have to design this exchanger using Bell's method.

Now, if I ask you that you are given the fouling factor of two fluids. So, which fluid you should allocate to shell side and which you should allocate to tube side. The fluid having more fouling tendency should be allocated to tube side. So, if you see the less fouling tendency fluid is kerosene in this case because it has lesser dirt factor as compared to crude. So that is basically 2 into 10 to the power – 4 which is less than that for crude stream.

So kerosene should be allocated to shell side and here we have some more information like tube dimensions are given where OD of the tube, ID of the tube and total length of the tube are given along with arrangement and that is triangular pitch. We have to assume h i as 920 watt meter square per degree Celsius. It means tube side heat transfer coefficient is already given.

So, we have to focus only on shell side because Bell's method is applicable to shell side only. Number of tubes are given as 300 and baffle spacing is given as D s / 5. Now in this problem heat transfer coefficient of tube side is already given. For example if you are not given the tube side heat transfer coefficient then for example if you are not given the heat transfer coefficient of tube side.

And you have been asked to design the shell and tube heat exchanger using Bell's method. So tube side calculation you should carry out as we have discussed in examples of Kern's method and then shell side calculations you have to carry out using Bell's method. So let us start the solution of this example. As you understand that Bell's method first consider heat transfer coefficient on ideal tube bank and then different correction factors are involved in this.

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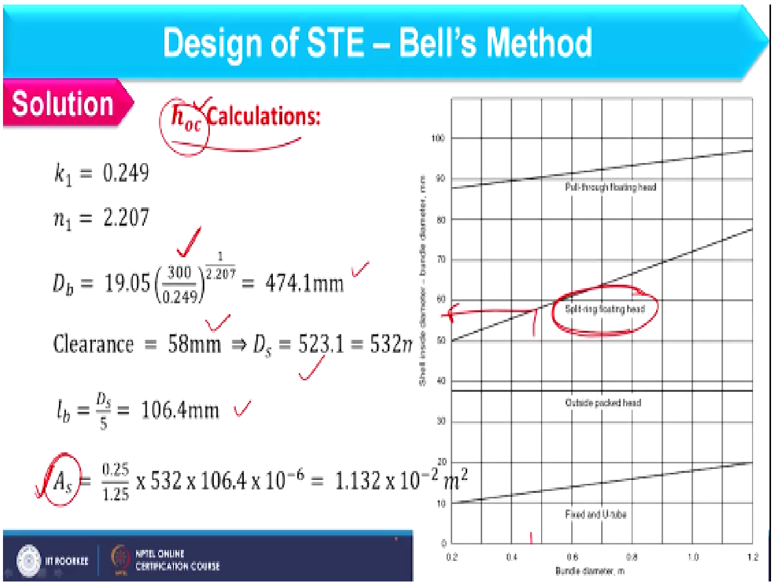

So, the first step is to find out h oc. So we have to consider calculations for h oc and this h oc will depend on u s and g s value which is as per Kern's method. So, first of all we should find out A s value and for that we should calculate baffle spacing and shell dia. So, to find out shell dia we should first find out the bundle dia depending upon the arrangement and the passes. So here I am having 1-2 pass and arrangement is triangular.

So you can consider k 1 and n 1 values like this. So you can consider k 1 and n 1 values like this and these values can be used to find out bundle dia because 300 tubes are given to you. So bundle dia you have found as 474.1 mm and then you can find out the clearance. So here as far as exchanger is concerned split ring floating head is given to you and the bundle diameter you have already obtained as 0.47 so that will be somewhere here.

So, you can understand the value from this graph and that value you can obtain as 58 mm and so you can calculate shell dia and further if you have the shell dia baffle spacing is given as D s / 5 so you can consider baffle spacing like this and then you can find out cross flow area that is A s which comes out as 0.01132 meter square. So, in this way you can calculate the cross flow area and now you should find out velocity Reynolds number j h factor and heat transfer coefficient that is h oc.

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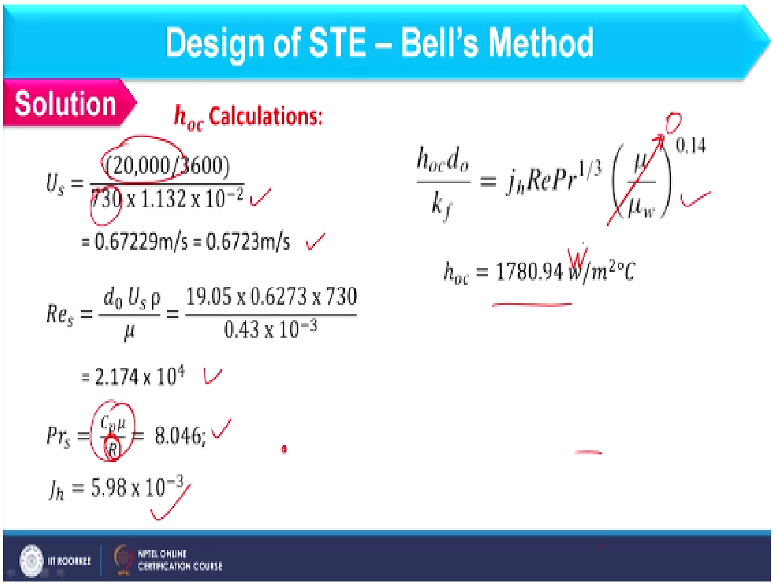

So, velocity of shell side you can find considering kerosene flow rate because that is allocated to shell side only its density as well as A s value considering all these you can find velocity in shell side at bundle equator as 0.6723. Now, if you see this problem here we are already given the properties because the collection of property we have already discussed in Kern's method in detail and in the similar line you can find the properties of the fluid.

And it is the repeated calculation I am not going into detail of that I am already providing you the properties assuming that you can collect the property in the given method as we have discussed in Kern's method. So, once you have the shell side velocity you can calculate Reynolds number which you can find as 2.174 into 10 to the power 4 so that is basically the turbulent region.

Prandtl number you can find out because all properties are known to you so this is not R it should be K that should be the thermal conductivity of the fluid. So, Prandtl number you can obtain as 8.046 so depending upon the Reynolds number like 2.17 so somewhere it will lie over here and here you can read this value so value will come almost equal to 6. So, value of j h you can obtain as 5.98 into 10 to the power – 3.

So, considering all these value you can use this expression where you can neglect viscosity correction factor and h oc you can obtain as 1780.94 watt per meter square degree Celsius here this W should be capital so in this way you can find out h oc value.

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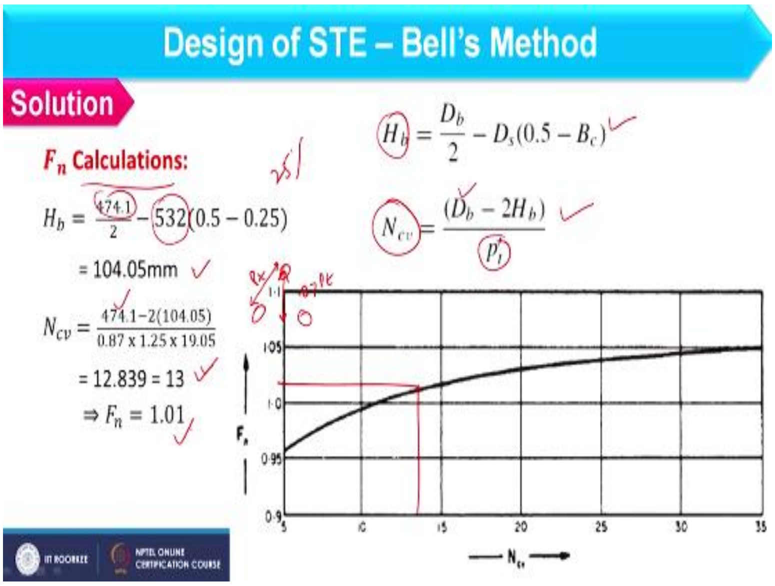

Now once you have h oc value we should find out other correction factors and let us see how to find out F n F w F b and F L. So let us start with F n value. So here I am having F n calculation and you have already seen that fluid is falling in turbulent flow. So we have to use the graph of F n for which N cv should be known to me. So to find out N cv we should consider H b. So first of all I will find out H b using this expression.

So bundle diameter you have already calculated and the shell diameter 0.5 into 0.25 because I am considering baffle spacing as 25%. So considering all these value, you can find out H b as 104.05 mm. Now once you have H b value you can find out N cv using this expression. So, here you already know the bundle diameter which is this and twice of H b I am considering and at bottom we have P t dash and if you see we are having triangular pitch so that should be arranged in this way.

So, total height between two rows should be 0.87 into P t if this is the P t. So considering this we can find out N cv as 12.839 and that I have considered as 13 because whatever N cv I have obtained that should be the complete number because N cv is the number tube rows and that can never be in decimal. So, what you have to do you have to round it up N cv should be round up.

So, whatever value you have obtained just consider next integer value of that and so we can obtain N cv as 13. Now once I am having N cv as 13 you can use this graph and somewhere here you can find the value and if you see the value will be around 1.01 if you find the value from this graph it should come as 1.01 F n value.

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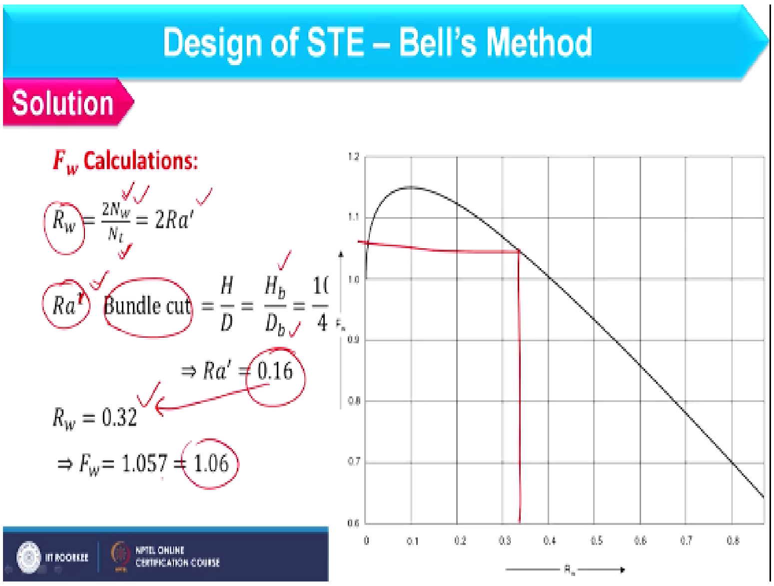

Next, I have to find out F w that is window correction factor. Now F w now to find out F w you should know R w because you are given the graph of F w and R w in books. So R w you can consider as 2 N w / N t N w is the number of tubes in window zone and N t is the number of tubes in bundle and that should be equal to 2 into R a dash. So, first of all I have to find out R a dash this is not one this is R a dash and we have already discussed that R a dash will depend on bundle cut and bundle cut how I can define that should be H b / D b.

So, all these parameters we have already discussed in Bell's method in lecture 2, 3 and 4 of this week. So you can understand this so I am simply explaining that how to use that instead of explaining each and every parameter. So, if I ask you what is bundle cut so that should be H b / D b and H b / D b values you have already calculated and so you can find the bundle cut as 0.22.

Now, if you have bundle cut you can find out R a dash from this graph so on X axis I am having the cut and on Y axis I am having R a dash value. So as far as cut is concerned your cut should be somewhere here because it is 0.22 and if you are considering this you can find out value of R a dash as 0.16 from this graph and once you are having R a dash 0.16 R a w you can find out as 0.32 just twice of that and once you have all these value you can trace R w over here that should be 0.33.

So, somewhere here it will lie and then you can read the value from here. So, the value should come as 1.06 so in this way you can find out window correction factor and now we will focus on bypass correction factor.

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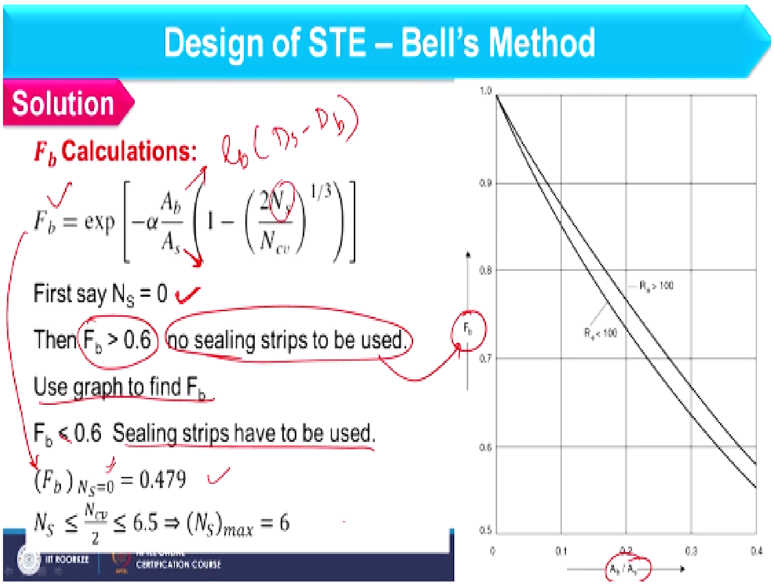

So as far as bypass correction factor is concerned here we have the expression for F b where number of sealing strips are given as N s. So, first of all we should find out whether sealing strips are required or not and to calculate that we should consider N s = 0 in this expression and to find F b value. So, considering N s = 0 we can find out F b based on A b and A s value. A b is basically the baffle spacing into D s – D b.

So, all these values are known to you so you can simply calculate A b. A s you have already calculated in h oc calculations and here I am having N s = 0 and for that so how we can find out whether sealing strips are required or not. For that I will put N s = 0 and then I will calculate F b value. If F b value is coming more than 0.6 no sealing strips are required and if this is the case where no sealing strips are required we have to find out correct F b value from this graph where A b / A s we have already calculated.

So in this case F b we can find out by graph. Now for N s = 0 if F b value we can obtain as less than or equal to 0.6 we should use sealing strips. So, in this case if I am putting N s = 0 in this expression so F b we can obtain as 0.479. So, in this case you can understand that F b is coming less than 0.6 it means we required sealing strips. So, how many sealing strip should be required the maximum will depend on N cv value.

Maximum number of sealing strip should be equal to or less than N cv / 2. Now in this problem N cv is given as 13. So, maximum N s value we can consider as 6. So you can consider different value of N s and you should stop where you will find F b value more than 0.85.

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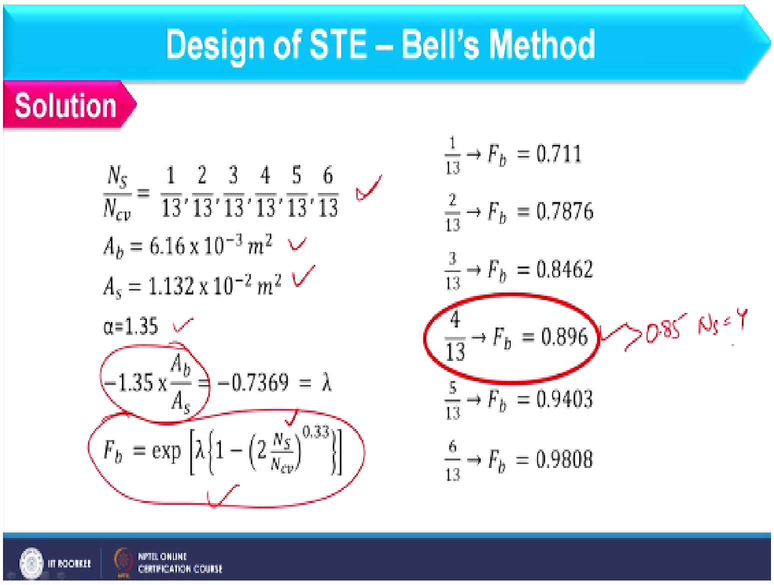

So, let us see the calculations if I am having N s and N cv like 1 / 13, 2 / 13 in this way. So further we can obtain A b and A s which we have already used in F b calculation in the last equation and here alpha value should be used as 1.35 depending upon the flow. So in this case we can consider this term in the expression as lambda and we can further reduce the F b expression like this where it is the function of N s and N cv.

So, considering different N s values because maximum N s I can use as 6 and different N s value we can consider to find out F b value and you can see we can have all F b values. So you can consider another approach also as we have already discussed in last lecture that sealing strip should be used in pair so that value should be even. So, initially I should consider N s = 2 then 4 and then 6 instead of 1, 2, 3, 4, 5. So you can do that also.

Now, if you consider different N s value where you should stop. As the guideline is F b value should be more than 0.85 so you can choose 4 number as sealing strips so N s should be 4 in this case because in this case F b value you can obtain as 0.896 which is more than 0.85. So, N s you can fix as 4. So now we can calculate leakage correction factor.

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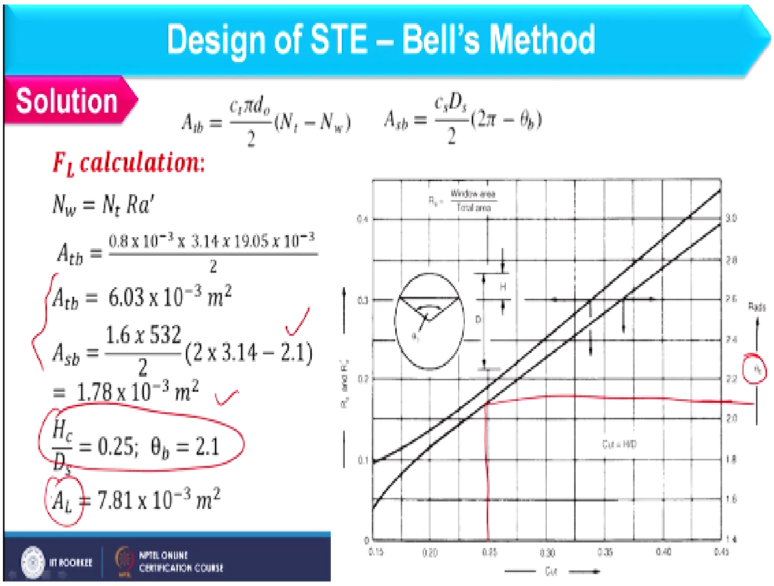

So as far as leakage correction factor is concerned we should calculate A tb and A sb so A tb and A sb expressions are given over here and here we require N w so N w should be N t into R a dash R a dash we have already calculated and A tb you can find out using this expression where c t is basically clearance between hole in baffle and tube OD. So this c t is always equal to 0.8 mm so in this way you can find out A tb value.

So, considering all these value and N w N w you can find as 48 so you can use this expression and you can find out A tb value as 6.03 into 10 to the power – 3. So, here we should also consider N t – N w N w over here is 48 N t is 300 and next we have to find out A sb value and to find out A sb we should also consider c s and theta b. So, c s how I can obtain c s will depend on the shell dia if you see in this problem the shell dia is 532.

So, it will fall in this range and in this range also, but I have told you if I have the choice between pipe shell and plate shell I should choose pipe shell. So, this is basically the c s value so depending upon the shell dia we can consider c s 1.6 as you can see here and next we have to find out theta b value and that theta b value we can obtain from this graph and this theta b value should be corresponding to baffle cut.

So, here I am having 0.25 because 25% baffle cut is there so you can simply see the value of theta b and that should come out as 2.1. Considering all these value, you can find out A sb and this is also mentioned over here that H c / D s is 0.25 that is basically the baffle cut and theta b should be 2.1. So considering all these values you can find out A L.

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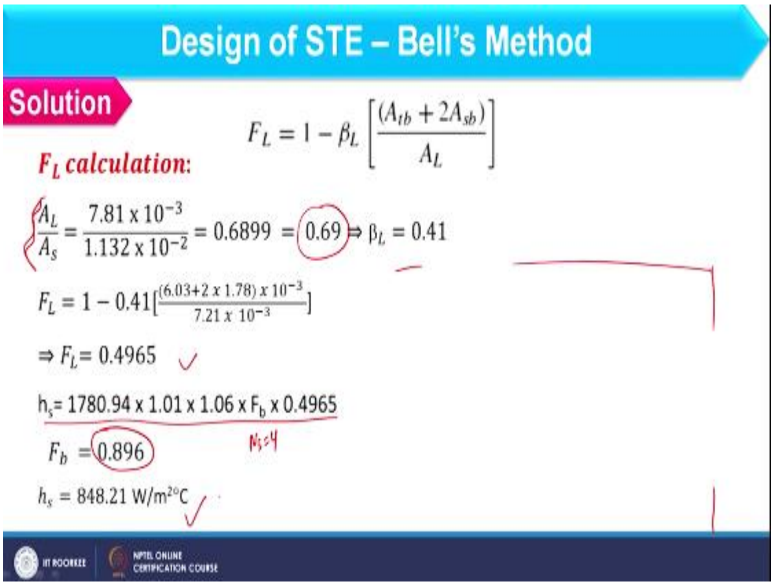

And further you can find out A L / A s and the value should come as 0.69. Depending upon that you can find out value of beta L from this graph so 0.69 somewhere it will lie here and if you see this value it should come as 0.41. So considering all these values, you can find F L value and which is coming as 4965. So considering F n F w F b and F L values, you can find out heat transfer coefficient in shell side by multiplying these with h oc value.

So you can consider H s as this so F b value at N s = 4 you can find as 0.896 this we have already discussed. So, heat transfer coefficient over shell side is 848.21 watt meter square degree Celsius. So that is basically heat transfer coefficient in shell side.

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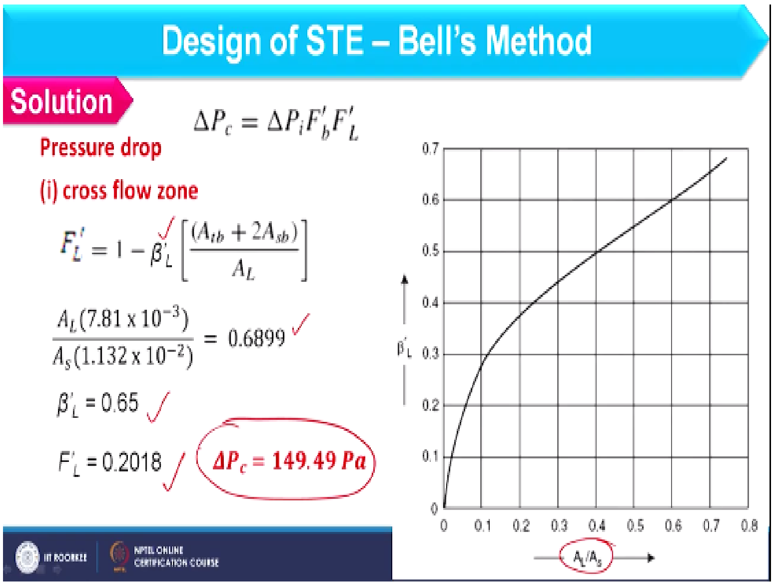

Now we should quickly cover pressure drop in shell side. Now as you know that pressure drop we should consider in cross flow zone, window zone and end zone separately. So let us start with cross flow zone so this is the expression for pressure drop in cross flow zone and delta P i is basically the pressure drop in ideal tube bank and that you can calculate using this equation.

So, here u s you already know N cv 13 and Reynolds number you can obtain like this and then you can find out j h value as shown over here. So, depending upon this you can find out delta P i value as 1026.014 pascal and after that you can find out F b dash as well as F L dash. So F b dash for that you should consider alpha value otherwise all parameters will remain same. Number of sealing strips we have already fixed to 4 A b and A s value you can consider like this.

And putting all these values in F b dash you can find out bypass correction factor for pressure drop as 0.722 and for cross flow zone we should also find out leakage correction factor. So expression of leakage correction factor is same only beta L dash value will differ. So, you can find out beta L dash value from this graph depending upon A L / A s and all these value you have already calculated so that comes out as 0.69 and based on that beta L dash you can obtain as 0.65 so F L value you can consider as 0.2018.

So, delta P i F b dash and F L dash you can find out pressure drop in cross flow zone as 149.49 pascal.

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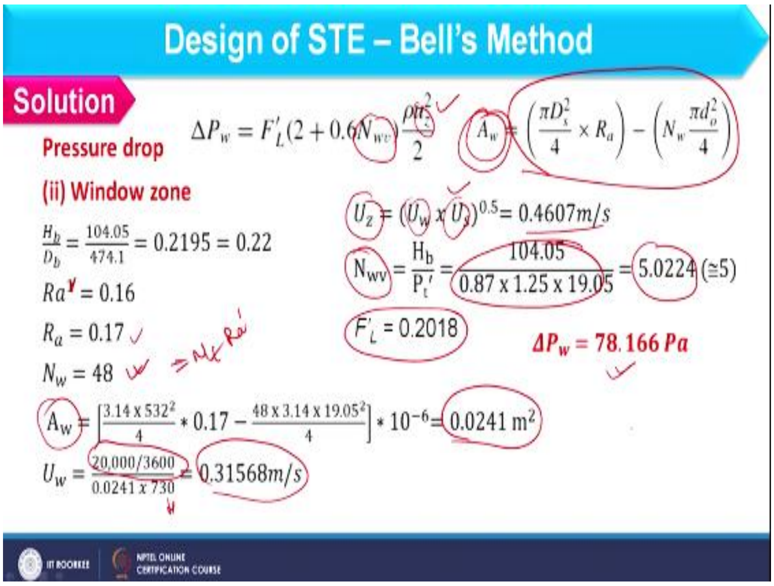

Now we have to find out pressure drop in window zone. So, this is the expression for pressure drop in window zone. Here I have to find out N wv and U z and U z is basically the geometric mean of U s and U w. So first of all we should find out U w and that will depend on A w and A w is basically the free flow area in window zone and that we can obtain by this expression.

So here we have to find out R a. So, once I am having bundle cut, we can find out R a dash and once I am having baffle cut we can find out R a using this graph. So, I think you can read this graph I am not going into detail of that. So considering that R a and R a dash you can find out N w and that you have already calculated previously so that should be equal to 48 and its value should be equal to N t into R a dash.

So, considering this we can find out A w which is coming as 0.0241 meter square. So, once you have A w value you already know the mass flow rate in shell side that is of kerosene and density of the kerosene you can find out U w as 0.31568 meter per second. So considering U w as well as U s which you have already found in h oc calculation so you can consider U z as 0.4607 meter per second.

And after that we should find out N wv that is the vertical tube rows in window zone and that should be equal to H b / P t dash H b we have already calculated and P t dash is 0.87 into P t because I am considering triangular pitch. So considering all these values we can find out N wv as 5.0224 and here you should keep in mind that N wv should be round off because N wv is the vertical tube rows which will never be in a decimal.

So, if you consider N cv that was also the vertical tube rows that we have made round up so N wv should be round off or you can do vice-versa also like N wv should be round up or N cv should be round off because if both values you make round off or round up the number of tube rows will be different in bundle. So, here we have considered N wv as 5 so leakage correction factor we have already calculated.

So, putting all these value in delta P w we can obtain pressure drop in window zone as 78.166 pascal.

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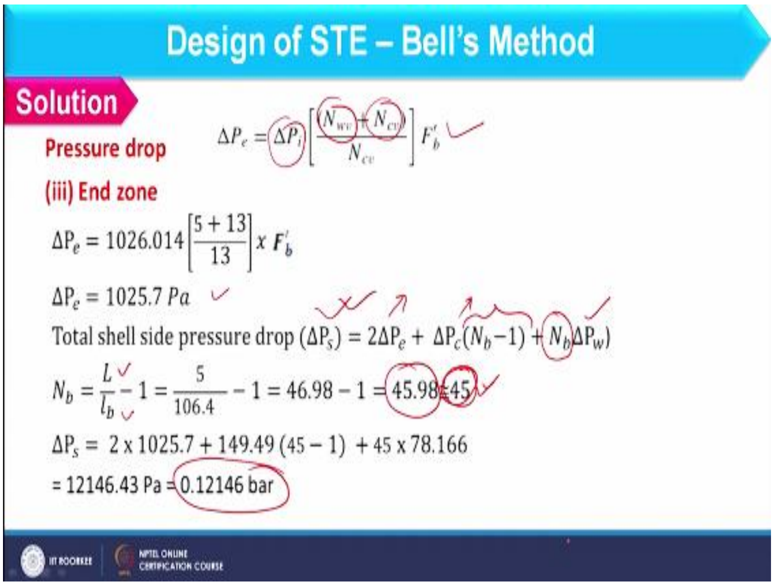

And further we have to find out pressure drop in end zone and the expression for that is given over here where N wv is 5 and N cv is 13 delta P i we have already calculated previously. So considering all these values, you can find out delta P e as 1025.7 pascal. So, total shell side pressure drop that is delta P s should be equal to 2 into delta P e because we are having two end zone.

Delta P c that is the pressure drop in cross flow zone into total cross flow zones and similarly pressure drop in window zone into total window zone in shell. So, here we have to find out N b value so N b value that is the number of baffles and that should be equal to capital L / l b – 1 so you can find out 45.98 as N b. So because it is very close to 46 you can consider 46 also, but here I am considering 45 as the length of the shell is fixed so N b should be round off.

So, here I am considering 45 as number of baffles. So, putting all these value in this expression we can find out total pressure drop in shell side as 0.12146 bar which is very less than one bar which is known as the permissible limit in shell side if you read the example. So in this way you can consider Bell’s method to design the shell and tube heat exchanger.

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And here you can find the references to study details about this method and here I am summarizing this video.

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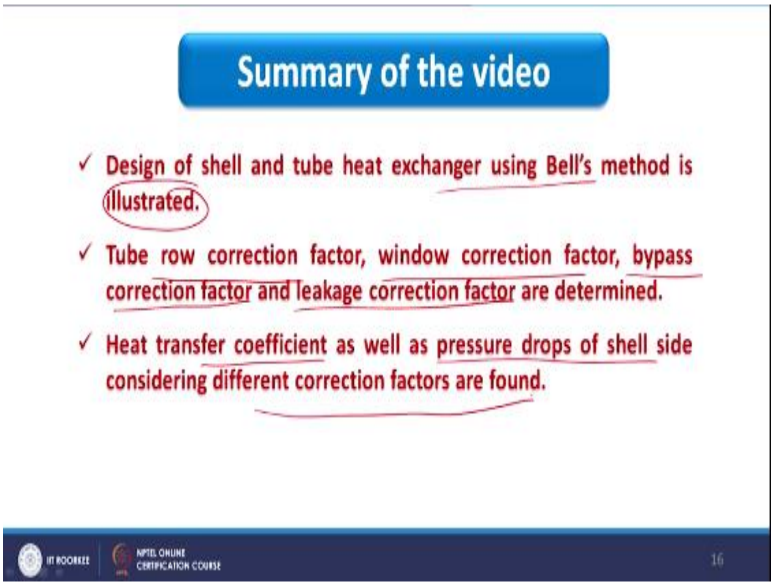

So, in this video design of shell and tube heat exchanging using Bell's method is illustrated with the help of one example where tube row correction factor, window correction factor, bypass correction factor and leakage correction factors are determined and finally heat transfer coefficient as well as pressure drop in shell drop considering different correction factors are found.

So, I hope you can use the Bell's method to design shell and tube heat exchanger effectively and that is all for now. Thank you.