Process Equipment Design
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Lecture –21
STE Design – Bell's Method Example-5

Hello everyone. Welcome to the 5th week of the course Process Equipment Design and here we are with lecture 21 and this is the first lecture of 5th week and here we are going to discuss design of shell and tube heat exchanger using Bell's method. In 4th week, we have discussed design of shell and tube heat exchanger using Bell's method and different steps involved in that and further we have seen one example in 5th lecture of last week.

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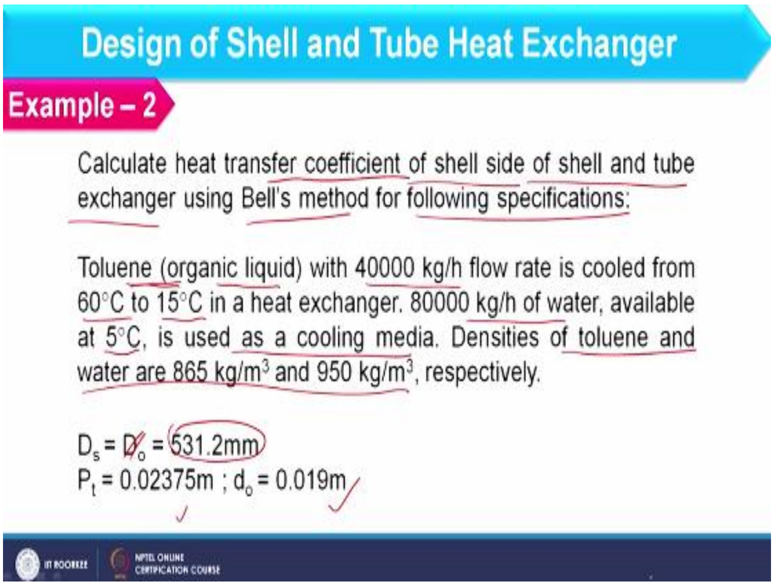

And here we are illustrating the design of exchanger using Bell's method with few more examples. So, let us start with example 2. So, in this example you have to calculate heat transfer coefficient of shell side of a shell and tube heat exchanger using Bell's method for following specifications. Here, we have to consider toluene which is basically an organic liquid with 40,000 kg per hour flow rate.

And it is cooled from 60 degree to 15 degree Celsius in a heat exchange. 80,000 kg per hour of water is used which is available at 5 degree Celsius and this we can consider as cooling media. Densities of toluene and water are given like this and here we are given shell dia as 531.2 mm and this is not OD this is basically shell dia. Pitch is given as 0.2375 meter and outer diameter of tube is given as 19 mm.

So, you see here we are given some specification about the problem and if you see this problem this is the same problem which we have discussed in 4th week and if you see the first lecture of that week where we have illustrated the design of shell and tube heat exchanger using Kern's method. So, the same example I am considering over here, but here we should apply Bell's method.

So as far as heat transfer coefficient and tube side is concerned that you have already covered in the first lecture of week 4. So, I am not going into detail of that, I am starting from Bell's method when it should be considered to shell side heat transfer coefficient. So, let us start this. So, here as you know that when we apply Bell's method the first parameter we have to obtain is h oc which is the heat transfer coefficient on ideal tube bank.

And then we will add other correction factors to find out actual shell side heat transfer coefficient.

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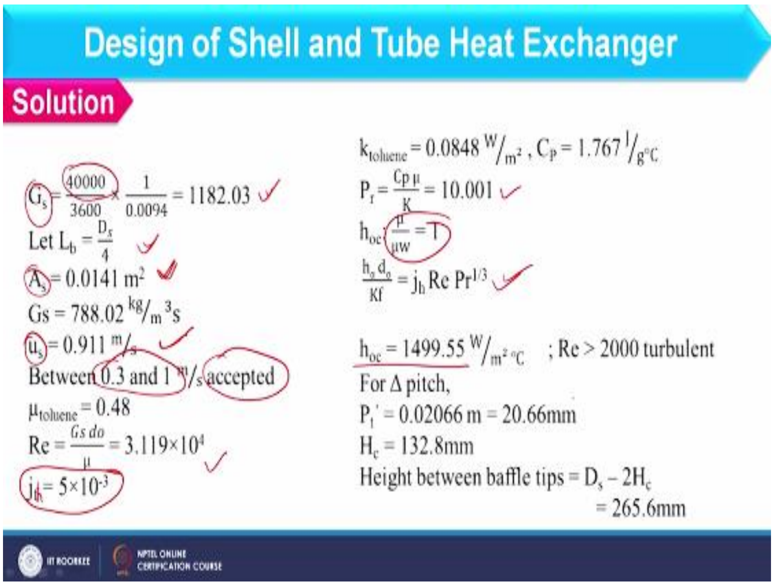

So, if you see when we calculate G s we have considered 40,000 kg per hour as the mass flow rate and which is of toluene because when I compare toluene and water you can understand that water is more corrosive, water has more faulting tendency so it should be allocated to tube side. So, toluene should be considered in shell side. So, considering that we can find out G s value which comes out as 1182.03.

And further we have to find out baffle spacing. So, here I am considering D s / 4 and I can also find out cross flow area that is A s which is basically based on baffle spacing as well as shell dia. So, A s value you can obtain as we have discussed in previous examples in Bell's method and Kern's method. Considering these, we can obtain shell side velocity as 0.911 and that should be U s.

So, if I compare this velocity it is basically falling within the range because it should be within 0.321 meter per second. So, whatever U s we have obtained that we can accept and as far as viscosity of toluene is concerned because that will be used to find out Reynolds number and viscosity of toluene, water all these we have already seen in the first lecture of 4th week. So, we can simply use these values instead of collecting the properties again.

So, once you have the viscosity of toluene you can find out Reynolds number which is coming out as 3.119 into 10 is to the power 4 and corresponding to this we can find out j h factor. So, here it should be j h, so we can find out j h factor depending upon the Reynolds number and further we can find out Prandtl number so it comes as 10.001 and we can ignore viscosity correction factor so that I have (()) (05:46).

And further you can find out h oc value using this expression and value you can obtain as 1499.55 watt per meter square degree Celsius because I am having Reynolds number more than 2,000 and after that once I am having h oc value after that we have to find out different correction factor like F n F w F b and F L. So to start this, we should first focus on F n correction factor.

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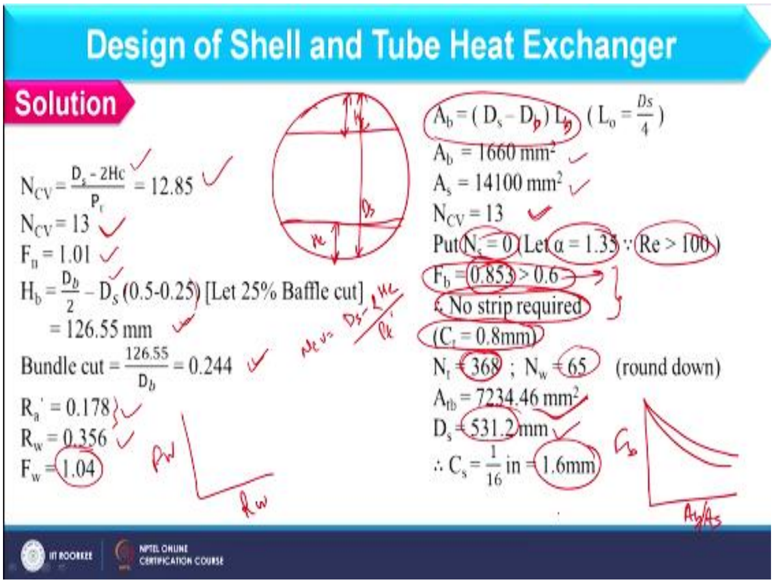

So let us start that. So, as far as this F n correction factor is concerned this will depend on N cv value because Reynolds number in shell side is more than 2,000. So, we have to find out F n value from the graph which will be based on N cv value. So, first of all let us focus on N cv value and this is the expression for N cv and here it is equal to D s – 2 H c / P t dash. So, if you see here we have considered slightly different expression.

Usually, it is D b – 2 H b / P t dash, but here I am considering D s – 2 H c / P t dash. Now, if you consider the cross sectional view of shell here I am having the baffle. This is the complete cross section of shell and this is basically H c value. So, D s is this and H c is basically the height of cut section of baffle. So, this is D s, if I am considering baffle cut of another baffle this is further H c.

So, N cv is what? N cv is basically number of tube rows between two baffle tips. So that I can find as D s – 2 H c also / P t dash. So, both formula will be applicable either you use D b – 2 H b / P t dash or you can use D s – 2 H c / P t dash in both way we can find same H cv value. So, considering these parameters because I already know D s I also have calculated H c value which is 132.8.

So, considering all these value we can find out N cv as 12.85 which should be round up and the final value of N cv I am considering as 13. So, you can find out F n from the graph of F n and N cv. So, F n value you can find as 1.01. So, now we have to find out window correction factor and for that I should know R a dash. I hope you remember all graphs and steps. Now, if I need to know R a dash I have to find out bundle cut.

And bundle cut will be nothing, but H b / D b. So, here you have to find out H b value again. So, H b should be equal to D b / 2 – D s bracket 0.5 – 0.25 because I am considering 25% baffle cut. So, you can find out H b value and then bundle cut you can find as 0.244. So, value of bundle cut you can find out depending upon the number of tubes and this is already available in first lecture of week 4.

So, for all these calculation you can please go through that lecture so that you can understand, but I hope if number of tubes are given to you, you can find out bundle diameter. So, here I am having baffle cut as 0.244 and based on that I can find out R a dash which comes out as 0.178 and so we can find out R w just twice of R a dash and after that we can consider graph of F w.

If you remember we have seen the graph of F w as well as R w. So, you can find out F w value as 1.04 and further we can see bypass correction factor as well as leakage correction factor. Now, if you consider bypass correction factor we have to find out whether sealing strips are required or not and that checking of sealing strip whether it is required or not that method is already explained in the last lecture that is the 5th lecture of 4th week.

So, you can please go through that. If you consider the F b expression there I am having alpha A b / A s and we have N s / N cv. So, maximum number of sealing strips you can use as 6 because N cv you can have is 13. So A b and A s the way we have obtained that in the 5th lecture of week 4 in the same line you can find here also. So, considering all these value if I am putting N s = 0 in F b depending upon the obtained value of F b you can decide whether sealing strip is required or not.

So, let us see that calculation A b you can find out by this where this is L b and that should be equal to D s and – D b. So A b you can find out as this and A s you have already obtained like this and N cv you have already obtained as 13 and when I am putting N s = 0 in F b expression. Actually here I am not showing F b expression because that expression is known to you.

So, I have directly put the value in the expression and here I am showing the values directly. So, if you are using N s = 0 in F b alpha here is 1.35 as you have Reynolds number more than

100. So, you can find out F b value as 0.853 and you can see that this value is already more than 0.6. It means sealing strips are not required in this case sealing strips are not required. So, here I am considering F b value as 0.853 only.

But here you should find revised F b value from the graph and that graph is between F b and here I am having A b / A s. So, value you can obtain from this graph depending upon the Reynolds number and that value you should consider as final F b value. So, please consider that here I am not considering that value and which is the mistake and I apologize for that because for further calculation I have used this value directly, but that is not the correct method. The correct method I have already explained to you.

So, please consider my apology for this. So, next we will find out leakage correction factor and for that you should find out value of A tb and A sb and in A tb expression you should use C t which is equal to 0.8 mm which is the fixed value in all cases and in A sb you have to find out C s value. So, you consider C t as 0.8 mm.

We have total number of tubes as 368 and N w we can find out as 65 and A tb you can consider as 7234.46 mm square, shell diameter is already given to you. So corresponding to shell diameter you can find out C s value from the table where shell dia and baffle dia are given as per the shell dia range.

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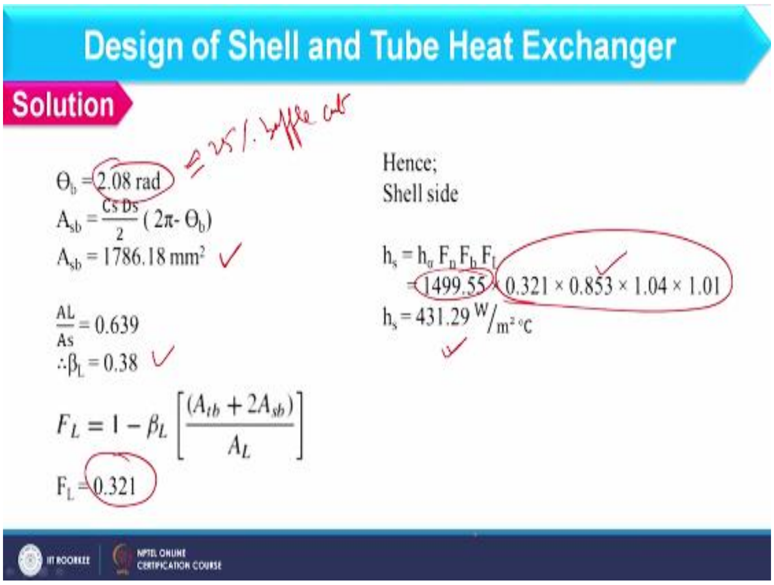

So, depending upon all these value you can find out A tb and A sb, but for that you also require theta b value. So that theta b value you can obtain as 2.08 and which is corresponding to 25% baffle cut. So, you can find out A sb value as 1786.18 mm square and then you can find out beta L value from the graph and so the F L value so F L value comes over here as 0.321. So, now you have all four correction factors and h oc value. So, you can find out shell side heat transfer coefficient by simply multiplication of all this.

So, simply you have multiplied all values of correction factors with h oc and here you see I have consider F b as 0.853, but you should consider F b value from the graph and then you should use that value here. So, final heat transfer coefficient in shell side you can obtain as 431.29 watt per meter square degree Celsius. So, this is the solution of example 2. Now, I am considering another example where we are using Bell's method to find out pressure drop.

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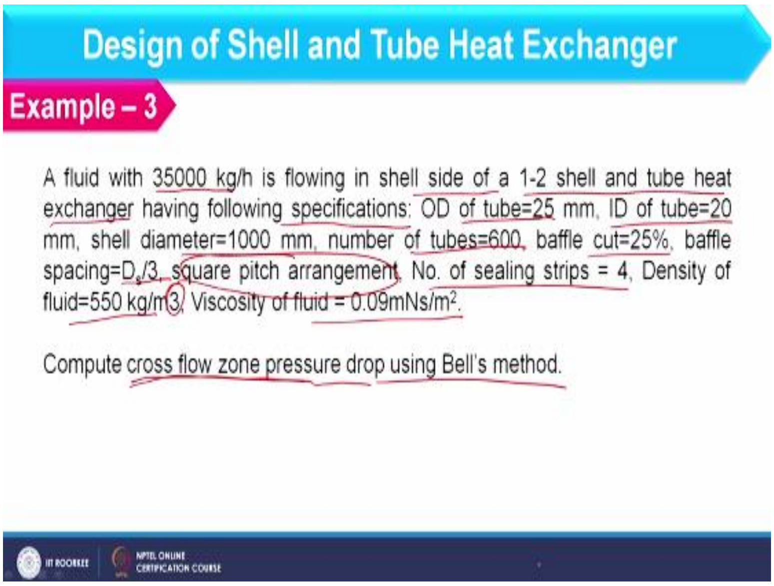

So, here I am having example 3 as a fluid with 35,000 kg per hour is flowing in shell side of 1-2 shell and tube heat exchanger having following specifications where OD of the tube is 25 mm, ID of the tube is 20 mm, shell diameter 1,000 mm, number of tubes are 600, baffle cut 25% and baffle spacing D s / 3. Square pitch arrangement are given and number of sealing strips are 4.

So here we have already fixed the number of sealing strips. So, here we have already fixed the number of sealing strips. Density of the fluid is 550 kg per meter cube and viscosity of the fluid is 0.09 millinewton second per meter square and what we have to compute is cross flow zone pressure drop using Bell's method. So, for this problem we have to find out cross flow zone pressure drop.

And for that you need bypass correction factor as well as leakage correction factor. So, let us start the calculation. So, when you consider the pressure drop in cross flow zone you have to find out delta P i and delta P i is basically the pressure drop in ideal tube bank. Now, if you recall the expression of delta P i it consists N cv U s and other parameters. So we have to find out u s that is the shell side velocity at bundle at bundle equator and that will depend on A s value.

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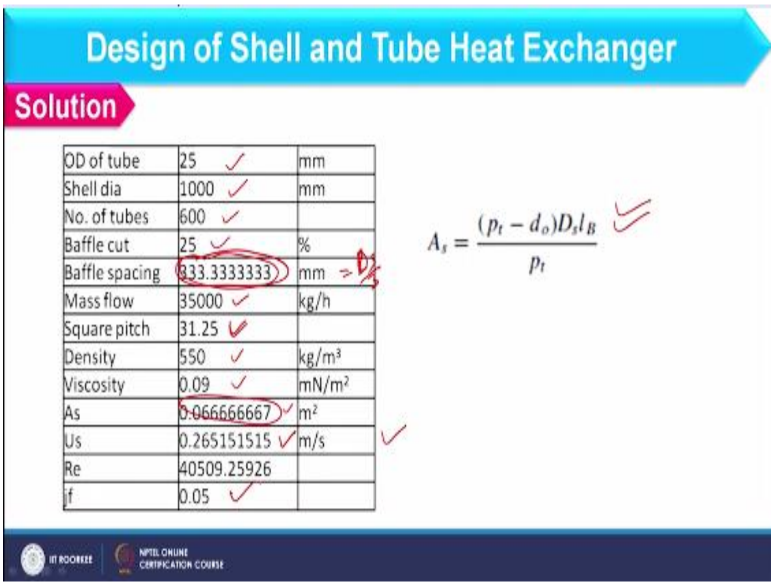

So, let us start the solution of this problem if you see here I am having OD of the tube as 25 mm, shell dia 1,000 mm as given, number of tubes are given as 600, baffle cut 25% and baffle spacing which is equal to D s / 3. So 1,000 D s is given so 333.33 is the baffle spacing, mass flow rate is given to us which is 35,000, square pitch because 25 mm is the OD so you can find out the pitch which is 1.25 into OD.

Density of the fluid is 550, viscosity 0.09 and here we have all expression to calculate A s and A s you can find out using this expression and value of A s you can consider as 0.0667 meter square and in the similar line we can find out shell side velocity at bundle equator which comes out as 0.26515 meter per second. So, considering shell side velocity as well as the property you can find out Reynolds number of shell side.

And it comes out as 40509.25 which is in the turbulent zone and you can consider j f factor to find out delta P i and the j f factor you can obtain from the same graph which we have used in 5th lecture of 4th week. So that we have already illustrated. So, I am considering value of j f directly which comes out as 0.05. So, if you see we have already obtained U s value. Now we have to find out N cv because then only I can calculate delta P i.

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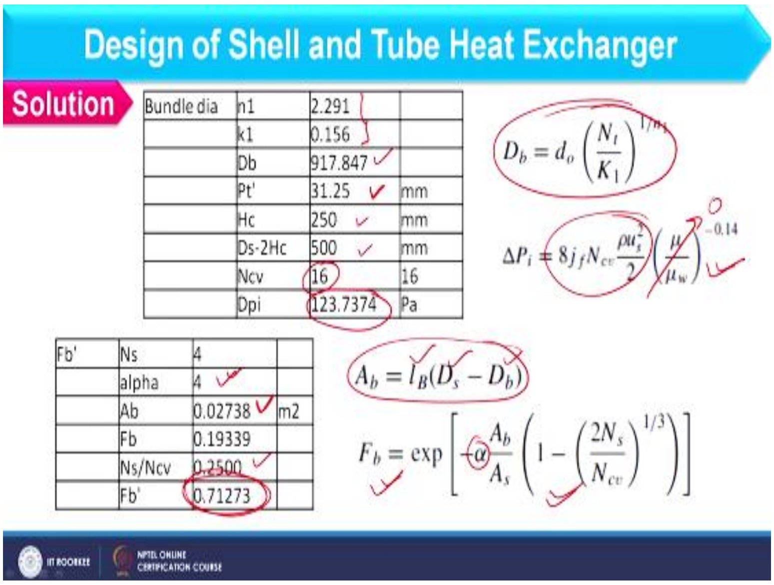

So to find out N cv we have to find out bundle diameter. So, OD of the tube is given and number of tubes are also given which is equal to 600. So, you can consider 1-2 pass and for that k 1 and n 1 value you can obtain corresponding to square pitch and bundle diameter corresponding to 600 tubes you can find using this expression. So, there is nothing new you have already used this expression many times before.

P t dash you can also consider as equal to P t because I am having square pitch now. So, H c value you can consider as 250 D s – 2 H c you can find as 500 and N cv value based on all these you can find as 16 which is basically the total number so you do not have to do anything, you should consider N cv 16 directly. So, once you have N cv value you can find out pressure tube in ideal tube bank using this expression and neglecting viscosity correction factor.

So, based on all these value you can find out pressure drop in ideal tube bank and which is coming out as 123.737 pascal and now we will further calculate bypass correction factor as well as leakage correction factor. So, let us start with bypass correction factor. Now in this problem number of sealing strips are already fixed which is equal to 4 and you have this expression of F b where alpha value is equal to 4 also because it is in the turbulent zone.

So, A b you can obtain from this because you already know D s D b and L b. So A b value you can obtain. Now, considering N s = 4 and N cv as 16 you can find out N s / N cv as 0.25 and then considering all these values in this expression you can find out F b dash as 0.7127. So in that way you can find out bypass correction factor for pressure drop calculation. Therefore, we are considering F b prime.

In the similar line, we should also carry out F L prime that is leakage correction factor for pressure drop.

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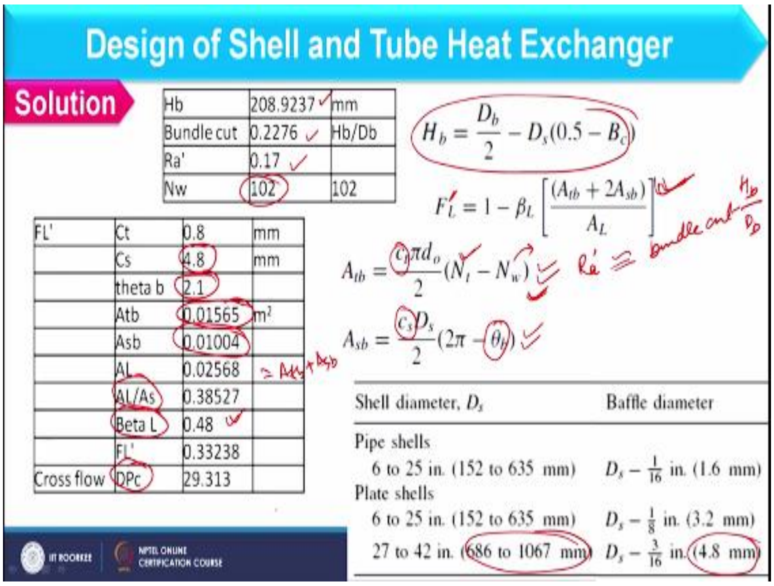

So, to consider that we can use this expression that is F L prime should be equal to 1 – beta L A tb + 2 A sb / A L and A tb expression is given over here and A sb expression is given over here which you have already used previously so I am not going into detail of this. Just I am telling that how we can obtain different parameters. So, C t value is already fixed as 0.8 N t 600 is already given.

Now you have to find out N w and for that you have to find out R a dash because N w is equal to N t into R a dash and for that R a dash you have to find out bundle cut and that should be equal to H b / D b. So, first of all you have to find out H b using this expression and the value of H b comes as 208.92. Once you have this value H b / D b you can consider which is coming as 0.2276 as bundle cut.

And based on that you can find out R a dash value as 0.17. Now once you have R a dash value and total number of tubes you can find out N w as 102. So, based on that you can find out A tb value which is coming out as 0.01565 meter square and further I have to find out A sb and for that theta b value should be seen from the graph along with this C s is also required.

So, what should be the C s value? For that we should consider this table where the diameter is 1,000 so which will fall in this range and if I consider C s value this should be the C s value. So, in this case C s value should be 4.8 and considering baffle cut you can find out value of theta b from the graph. So, baffle cut is 25% and theta b we can obtain from the graph as 2.1 which we have also seen in last lecture of 4th week.

So you can go through that lecture and considering all these value I can find out A sb as 0.01004 and then we can consider A L which should be equal to A tb + A sb. So, addition of all these will give the value of A L and after that we can find out ratio of A L / A s and based on that I can see the value of beta L from the graph. So that value of beta L comes as 0.48 and based on that I can find out F L dash value using this equation which is coming at 0.3324.

And accordingly I can find out pressure drop in cross flow zone and that should be equal to delta P i into F b dash into F L dash. So, in this way you can find out pressure drop in cross flow zone and detail calculations of that I have already explained in the 5th lecture of week 4. However, here some of the steps I have skip because I assume that the method is clear to you and you can simply apply that method and that is the Bell's method.

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And here I am having some of the references and now as far as this lecture is concerned let me summarize this lecture. In this lecture, we have discussed two different problems. In the first problem, we have calculated shell side heat transfer coefficient using Bell's method and in second example we have discussed pressure drop of cross flow zone using Bell's method. So, I hope the method as well as examples are clear to you and you can apply Bell's method to design shell and tube heat exchanger and that is all for now. Thank you.