Process Equipment Design

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Lecture –16
STE Design- Kern's Method-Example-5

Hello everyone. Welcome to the 16th lecture of the course Process Equipment Design and this is the first lecture of fourth week of this course and in this lecture we will discuss another example to design shell and tube heat exchanger using Kern's method. If you remember the 15th lecture there also we have solved one example and here we will solve another example for design of shell and tube exchanger based on Kern's method.

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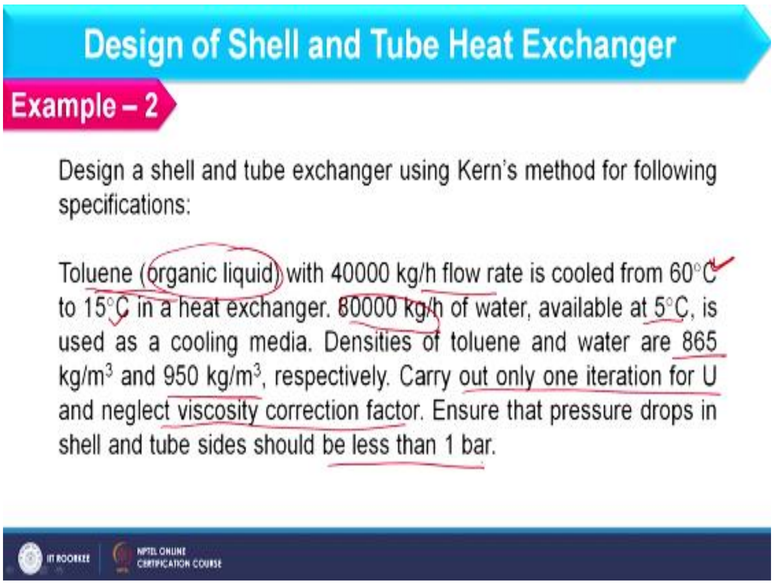

So, if you see this is example 2 and here the problem is like toluene which we consider as organic liquid is available at 40,000 kg per hour flow rate which is cooled from 60 to 15 degree Celsius in a heat exchanger where 80,000 kg per hour of water is used which is available at 5 degree Celsius as a cooling media. Density of toluene and water are given and carry out only one iteration for U and neglect viscosity correction factor.

Ensure that pressure drops in both shell and tube side should be less than 1 bar. So here we have the combination of toluene and water and in the previous lecture we have benzene and water combination. So the problem is similar to the previous problem only however some variations will be required over here that is why I have taken this example to illustrate the design. So, first of all we have to find out the heat duty and for that we have to find out specific heat.

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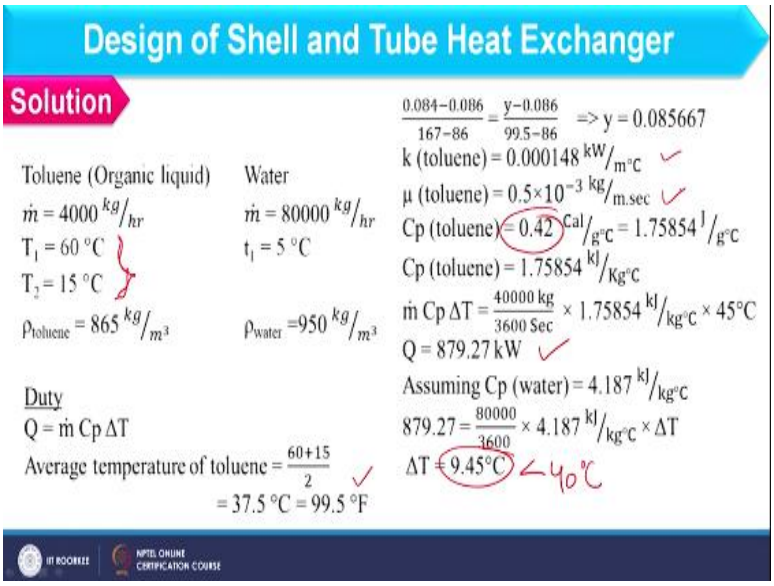

And to do that we have to first average the temperature of toluene. So if I do this T 1 and T 2 are available at 60 degree and 15 degree Celsius T 1 and T 2 are available at 60 degree and 15 degree Celsius so at average temperature you can find out the C p value or specific heat of toluene and which is coming as 0.42.

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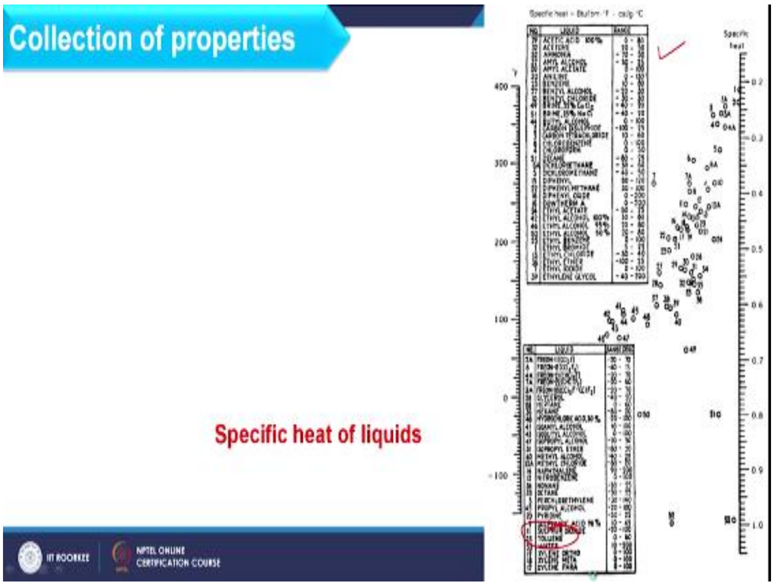

So this you can find out from this graph only. So here you can find toluene at this point which again consists the same number as of benzene. So you can simply find out that C p value based on average temperature of toluene. So considering this we can find out heat duty of the exchanger as 879.27 kilowatt and making the balance we can find out unknown temperature of the water which is coming less than 40 degree Celsius.

So, here you see the exit temperature of water is within the permissible limits if it exceeds from this limit you have to change the flow rate of the water and then we can find out other properties of toluene as well as benzene at average temperature. So, you can find out thermal conductivity and viscosity of toluene. Density is already given to us and in the similar line we can find out thermal conductivity and viscosity for water also using these graphs which I have already explained in previous lectures. So, you can use all these graphs.

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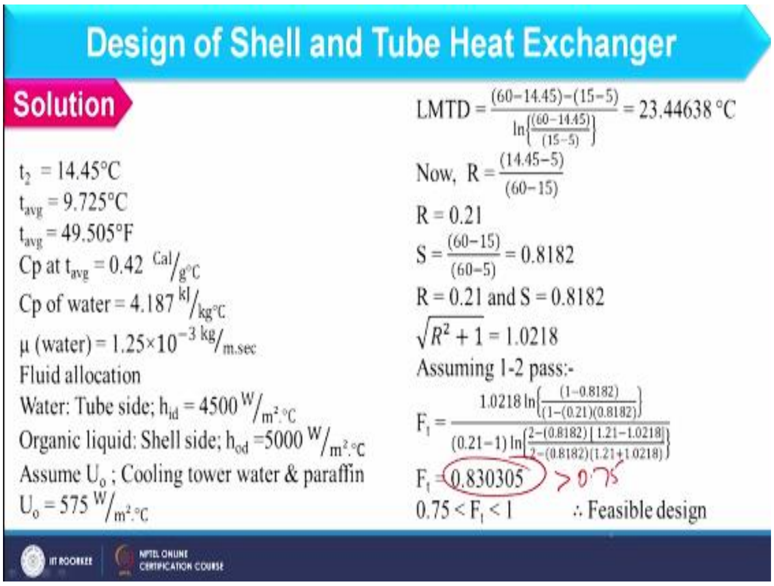

Now once you have all properties of both fluids along with the temperatures you can simply calculate LMTD value. So, LMTD you can obtain as 0.83 which is more than 0.75 so we can consider 1-2 pass only to start the calculation and next we have to find out overall heat transfer coefficient assumed value from this graph. So, again you can consider the fluids like this and you can find out the assumed value of U 0 and it will come as 575 as we have seen in the case of benzene and water.

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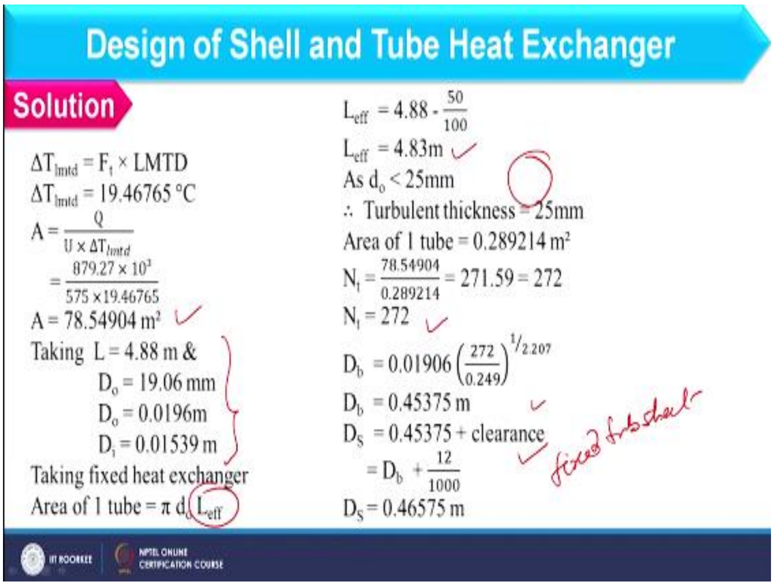

So you have LMTD value, you have F t correction factor so you have LMTD value, F t correction factor and overall heat transfer coefficient. So, now you can find the heat transfer area as 78.549 meter square. Tube length and diameter we can choose in the similar line as we have discussed in lecture 15 and next is we have to find out the number of tubes considering effective length.

So this is basically the effective length and total number of tubes we can obtain as 272. Next we have to find out the bundle diameter for 1-2 pass K 1 and n 1 value will be like this and based on these value you can find out bundle diameter as 0.45375 meter. So, clearance you can consider over here as the maximum temperature is 60 degree Celsius we should use fixed tube sheet.

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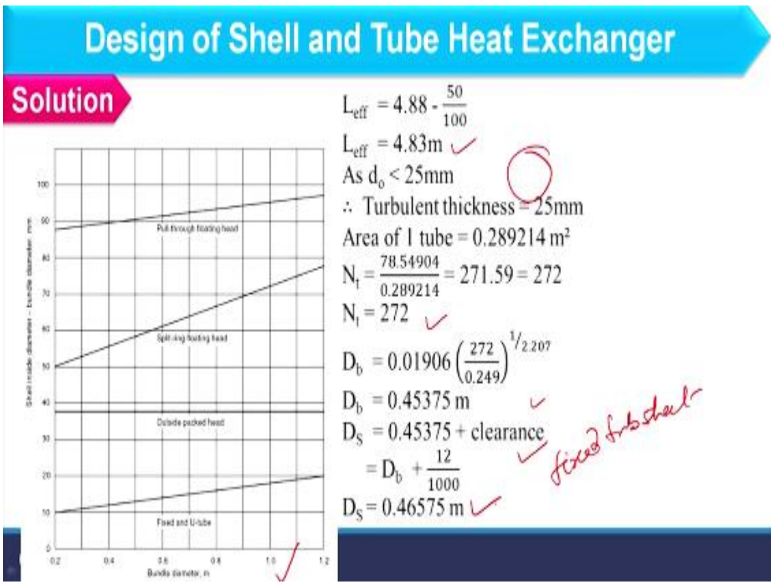

And you can use this graph for clearance. So adding this two bundle diameter we can obtain shell diameter as 0.465 or 466 meter.

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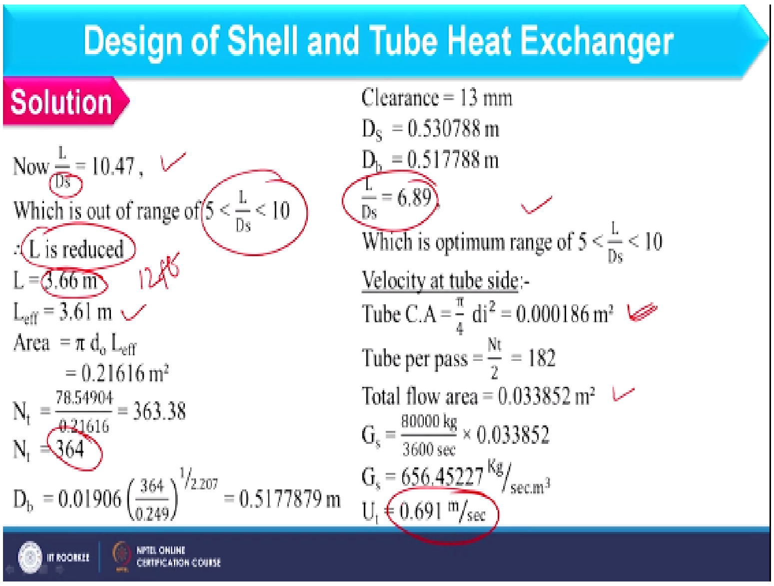

So in this way you can find out the bundle diameter and shell diameter and the next step is obviously to find out L / D ratio so that L / D ratio you can find as 10.47 which is not in this range. So you can do another thing also instead of reducing the length another option maybe we can increase the shell diameter. So you can use the diameter of the tube accordingly and then you can find out the bundle diameter and shell diameter and then L / D ratio.

But here I am reducing the length so next length is 12 feet and corresponding value is given over here. Effective length you can consider so now the number of tubes are 364. Considering clearance and bundle diameter L / D ratio now you can obtain as 6.85 which is within the range. So if you see that the dirt factor of toluene will be same as that of benzene in the last example or in the example discussed in lecture 15.

So, here I am considering water in tube side and toluene is in shell side. So let us continue the calculation with velocity in tube side. So cross sectional area you know already. So cross sectional area per tube you can find out and then you can find out total flow area because I am considering 1-2 pass. So velocity you can obtain as 0.691 I am not going into detail because this we have already discussed in lecture 15.

So just quickly I am covering this example. Now you see velocity is coming less than 0.691. So now you see velocity comes less than 1.5 meter per second. So what we have to do you know already we have to increase the passes. Now here I am increasing 1-4 pass. So, now you see when I am increasing the passes I am not calculating F t correction factor again because F t correction factor changes when I am changing the shell pass not the tube pass.

So until and unless shell pass will remain one F t factor will be same. So either it is 1-2 pass, 1-4, 1-6, 1-8 whatever you can take and total tube passes if you consider that can be up to 16 passes. So, here considering 1-4 pass we will consider same LMTD value and same area.

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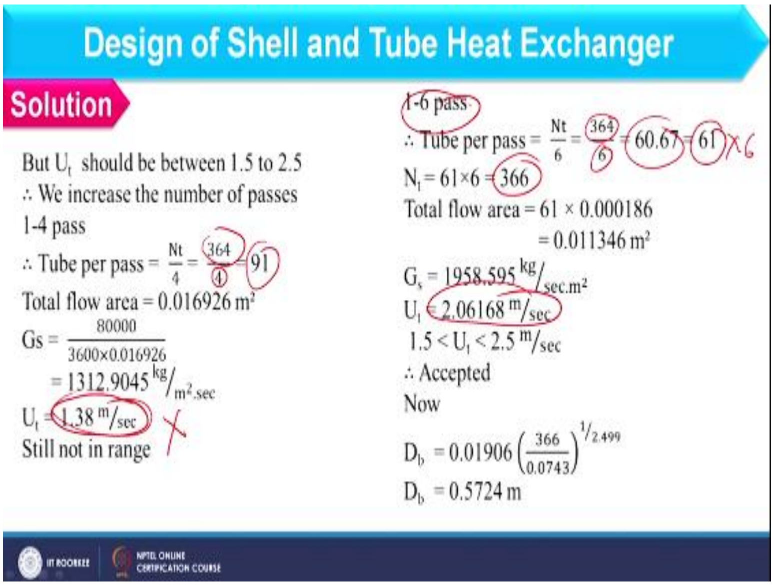

And we have number of tube as 364 which is divisible by 4 so 91 number of tubes can be allocated to one pass of the tube considering this we can find out the velocity of water as 1.38 meter per second. However, it is still not in range because range varies from 1.5 to 2.5 meter per second. So next step is again I have to increase the tube pass. So, now I am considering 1-6 pass. Now if you divide 364 tubes / 6 it will come in decimal.

So, we have to increase the number of tube then this should be multiplied by 6 we can obtain 366 number of tubes and in this case velocity you can find within the range and which is 2.062 meter per second and which we can consider for 1-6 pass. Now the passes are changed and we can obtain correct velocity of water. So what we have to do further because we have changed the passes bundle diameter, shell diameter will be changed and slightly number of tubes also.

So, considering all these variation we have to again ensure that L / D should fall within the permissible range. So, let us check that. So considering 366 tubes and 6 passes we can obtain

K 1 and n 1 value from this table and based on that bundle diameter we can obtain as 0.57 meter.

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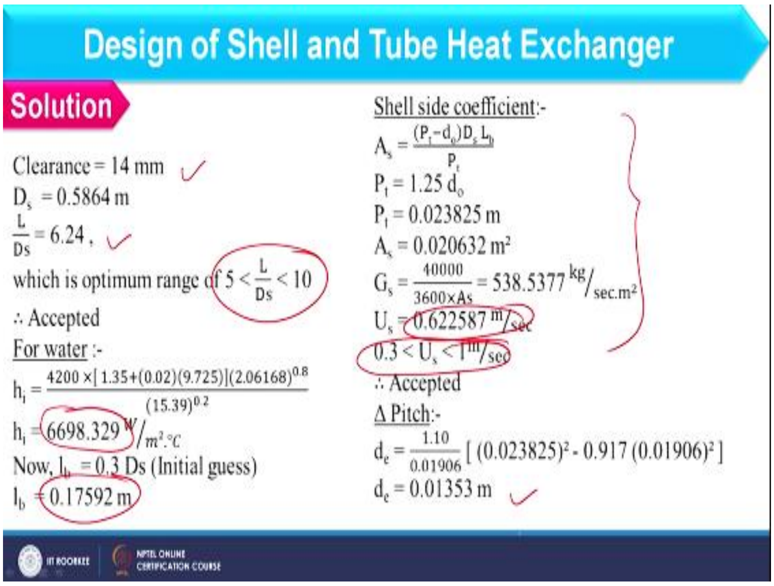

And clearance is again from the same graph we can obtain and that comes as 14 mm L / D ratio is 6.25 which is within the range. So, velocity and passes we can consider as the final or acceptable values and to calculate heat transfer coefficient in tube side we will use the expression which is especially given for water. So, heat transfer coefficient in water side or in tube side you can find as 6698.329 watt per meter square degree Celsius.

And then we have to carry out calculation for shell side heat transfer coefficient and for that we have to consider baffle spacing. The initial guess should be 0.3 into D s. So here you can find the baffle spacing like this and then we can follow the Kern's method the method is well explained to you and we can obtain the velocity as 0.622 meter per second which is within the range.

So this velocity is also accepted and we have to find out equivalent diameter also for triangular pitch. So equivalent diameter we can obtain as 13.53 mm.

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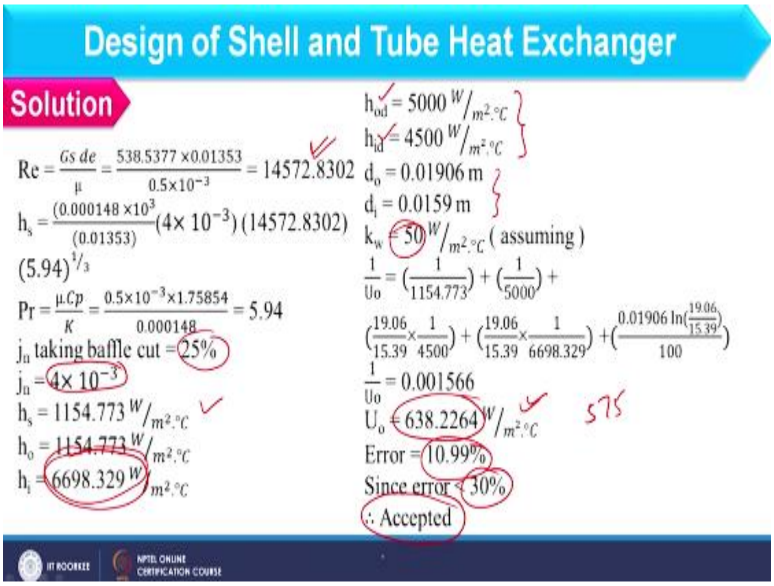

Considering all these parameters we can find out the Reynolds number as 1.45 into 10 to the power 4. So for this Reynolds number as well as baffle cut at 25% we can find out j h factor as 4 into 10 to the power – 3. As we also have discussed in lecture 15 so I am not going to tell you that how the graph will be used that you know already. Considering all these values, we can find out heat transfer coefficient in shell side as 1154.773 and h i that is heat transfer coefficient of water that we have already found.

And we can see the dirt factor from the table where fouling factors are available and that table I have also discussed in lecture 15. So I hope you can use that table and find the coefficient for dirt like this for shell side as well as for tube side or that is over the tube or inside the tube equivalent dia OD and ID of the tube you already know and thermal conductivity we have assumed as 50 watt per meter square degree Celsius.

And based on that overall heat transfer coefficient we can obtain as 638.226 watt per meter square degree Celsius. So, if you compare this with the assumed value which was 575 watt per meter square degree Celsius we can find error as around 11% which is less than 30% and so the heat transfer coefficient whatever you have calculated is acceptable.

So, once I am having heat transfer coefficient in shell side and tube side I have calculated overall heat transfer coefficient and compared with the assumed value. So, next step you know that we have to find out pressure drop in shell side and tube side.

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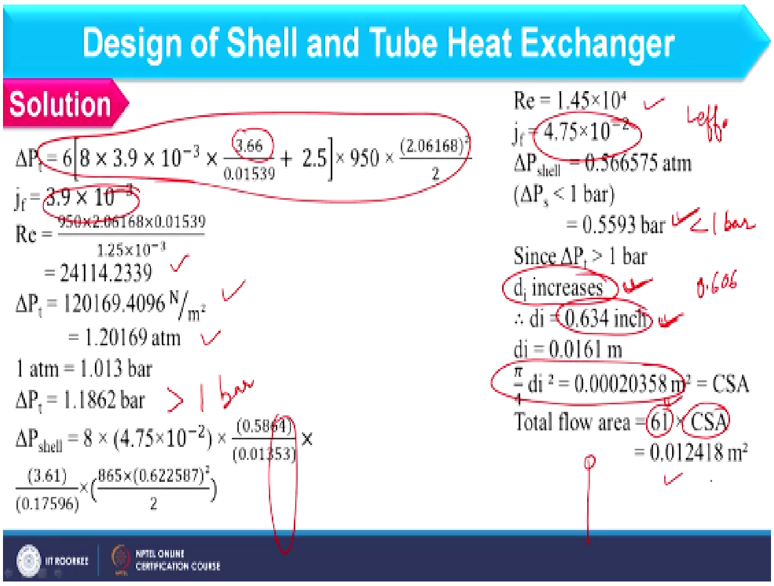

So, let us start this. So pressure drop in tube side the whole expression I have already discussed in lecture 15 and here I am simply applying that in the same expression and where complete length is considered so that is around 3.66 because we have considered 12 feet as a desired or acceptable length. So, here Reynolds number you can find as 2.4 into 10 to the power 4 so it will be somewhere here.

And if you consider this the value of j f you can obtain as 3.9 into 10 to the power – 3 from this graph only. So, if you carry out the calculation for pressure drop in tube side you can obtain the value as 1.20169 atmosphere and if I convert that into bar it comes as 1.186 bar and if I convert that into bar it comes as 1.186 bar so this value is more than one bar. So, you see the pressure drop in tube side is not in the range because it should be less than one bar.

We will further revise this section and for now we will compute pressure drop in shell side. So if I consider the Reynolds number in shell side that is 1.45 into 10 to the power 4 and we can use this graph so if you see I am having value 1.45 somewhere here and we have considered 25% as baffle cut. So, value you can obtain from here and that value will come as 4.75 into 10 to the power – 2 as you see this is the range of 10 to the power of – 2 10 to the power – 1.

So, accordingly you can find out shell side pressure drop and here you again have to consider L effective that you should keep in mind. Every time this will not be explained, but you have to keep in mind so do not make any mistake here and considering all these value shell side pressure drop we can obtain as 0.5593 bar which his less than 1 bar. So, shell side pressure drop you can obtain in a correct range however that is not in a range for tube side.

Now what I should do I have to maintain the pressure drop in tube side as well. So in this case we can have different options like we should reduce the tube passes, but when you will reduce tube pass you should also consider that in velocity and in that case velocity will be reduced. So here instead of changing the pressure drop we will change another parameter and that is d i of the tube and that must be increased.

Next, d i value I am considering as 0.634 inches previously we have considered value 0.606 and that is corresponding to BWG value as 15. So, if you increase the d i of the tube you have to decrease BWG value. So, I think you can use table B 1 effectively and find out d i which comes as like this and considering the inner diameter you can find out the total flow area where I am having 61 tubes in one pass and this we have obtained for 1-6 passes if you recall.

And that will be multiplied by cross sectional area of one tube which we have already obtained over here. So total flow area you can obtain as 0.012418 meter square. So now we have the total flow area now we can further find out the pressure drop or velocity in tube side.

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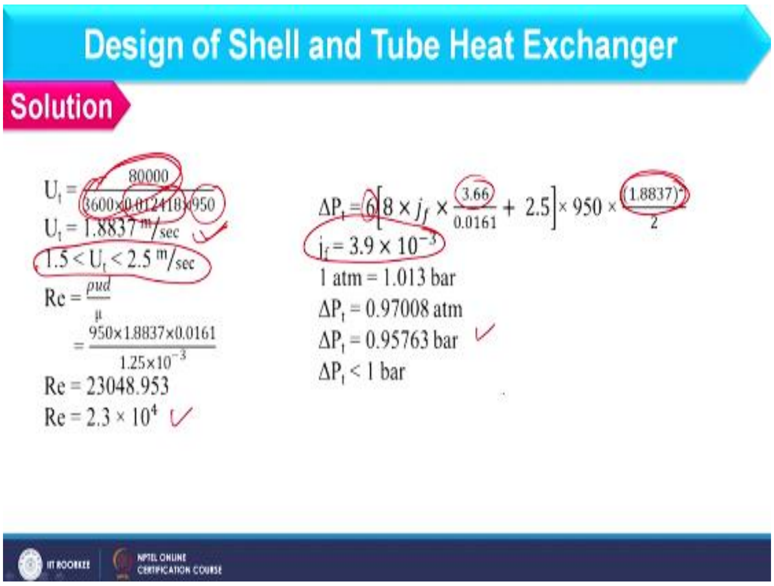

So, first of all we will proceed for velocity calculation so if you see we have 80,000 kg per hour of water and that I should consider in minutes. So that should be kg per second. So that I should consider in seconds so that should be kg per second and this is the flow area and 950 is the density of the water. Considering all these parameter I can find velocity as 1.8837 which is also in the range so that you can compare over here.

So, whatever d i I have chosen it is not giving velocity which is beyond the range. So I can consider d i whatever I have obtained as correct assumption. So, considering that we can find out the Reynolds number in tube side as it comes as 2.3 into 10 to the power 4. So based on that again we have to find out j f factor. So based on that again we have to find out j f factor from the graph and it comes as 3.9 into 10 to the power – 3.

Considering all these values that is the 6 passes and 3.66 the total length and the velocity which we have just obtained. So considering all these parameters, you can find out the pressure drop of tube side which now comes as 0.95763 bar. So you see here whatever pressure drop you have computed for tube side it is within the range. So, what you have to do next because you have changed the velocity.

So in that case you also have to check the changes obtained in heat transfer coefficient calculation because you have already changed the d i. So, it will not affect the shell dia because shell dia will depend on OD of the tube and OD of the tube is same that is 3 / 4 inches. So bundle dia, shell dia, L / D all these ratios or all these values are not changing only change we can obtain in heat transfer coefficient in tube side because here we have change in velocity.

So the variation in heat transfer coefficient in tube side and overall heat transfer coefficient and percent error you have to again obtain that value with the second iteration and you have to ensure that all these values are obtained in a permissible range. So, in this way you have to repeat this calculation which I am not showing over here assuming that part you can do on your own.

So here I have completed design of shell and tube heat exchanger using Kern's method with example 2. So up to now we have illustrated the design of shell and tube heat exchanger with total two examples and I hope concepts are clear to you. So you can carry out the design on your own.

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And here we have the references if you have any confusion you can go through this or you can simply tell us in forum we will definitely help you to design shell and tube heat exchanger which is not very easy because you already know the steps so usually we understand that steps are there we can find the values accordingly, but there are minor things which you have to keep in mind to carry out correct design so for that you have to follow these lectures along with the references I am showing.

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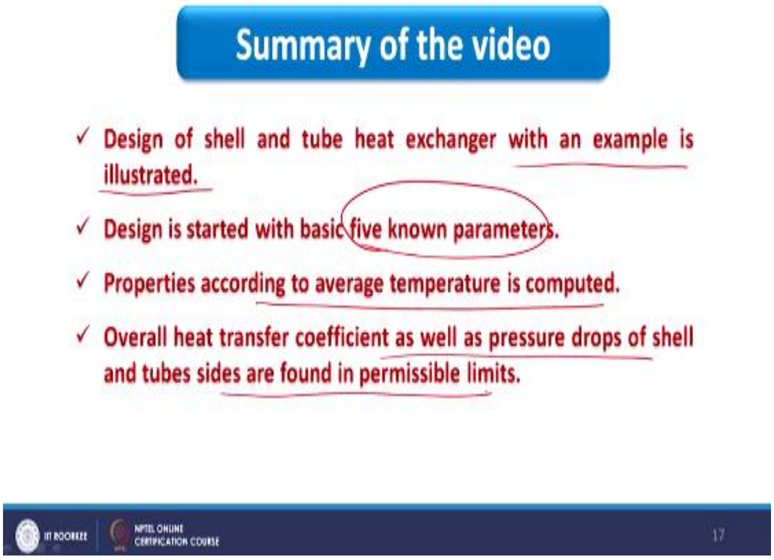

And here I have the summary of this video. In this video, we have design a shell and tube heat exchanger with example 2 where I am considering toluene and water combination. Design we have started with basic five parameters along with the density data and pressure drop range. Properties according to the average temperature we can obtain as we have already explained this in lecture 15.

Overall heat transfer coefficient as well as pressure drop of shell and tube side are found in permissible limit. Now, I would like to mention one more point that if pressure drop exceeds in shell side what you will do? In that case you have to reduce the pressure drop and that can be done by increasing baffle spacing and increasing baffle cut. So, these options you can consider while designing shell side and while calculating pressure drop in shell side. So that is all for now. Thank you.