Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology – Roorkee

Lecture –15
STE Design- Kern's Method-Example-4

Hello everyone. This is the 5th lecture of week 3 of the course Process Equipment Design and I welcome you all in this lecture. In the second, third and fourth lecture of this week we have discussed design of shell and tube heat exchanger using Kern's method and in this lecture we will illustrate the design of shell and tube heat exchanger with the help of one example.

And in this example you will understand that how we should consider the design of shell and tube heat exchanger using Kern's method and if you remember the last lectures we have discussed that whatever methods are available for design of shell and tube heat exchanger these methods are applicable shell side of heat exchanger. As far as tube side design is concerned, it is same for all methods.

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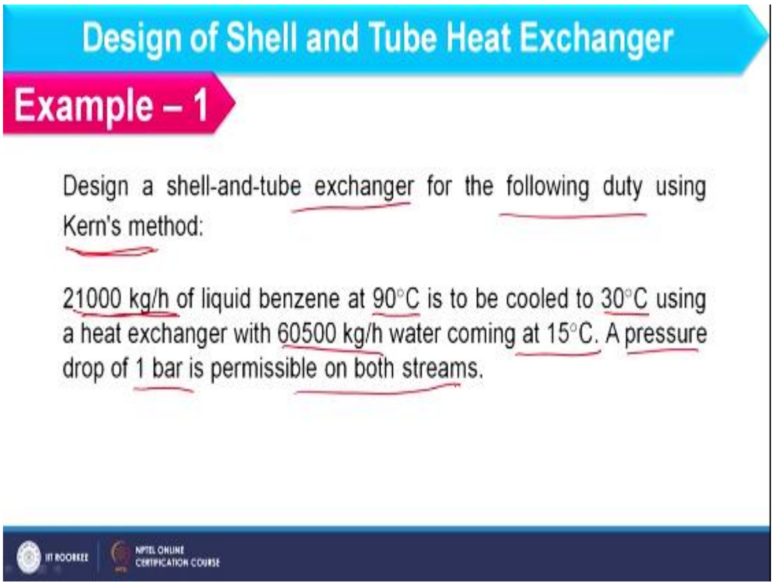

So, let us start the design of shell and tube heat exchanger using Kern's method with the following example. So, here I am having example 1 in which design a shell and tube heat exchanger should be carried out for following duty and that design I have to do using Kern's method. 21,000 kg per hour of liquid benzene which is available at 90 degree Celsius is to be cooled to 30 degree Celsius.

So, this benzene is basically the hot stream which is required to be cooled and that cooling should be done while exchanging the heat with 60,500 kg per hour of water which is available at 15 degree Celsius and further we are given that a pressure drop of one bar is permissible on both side. So, here you see the condition on pressure drop is already given to us and we have to design the shell and tube heat exchanger when liquid benzene is exchanging heat with water.

So one fluid is liquid, another fluid is water. So, if you see here we know only 5 parameters to start the design that is the flow rate and supply and target temperature of one liquid and flow rate of second fluid along with one temperature of it. So, we have to find out the second temperature of water and that we can do considering heat load. So, first of all we have to find out the heat load.

And you know that to calculate heat duty we have to find out specific heat of the liquid first. Now, if you see in this problem that for benzene I know both temperatures inlet and outlet temperature. So, simply I can do the averaging of both temperatures which is available for benzene.

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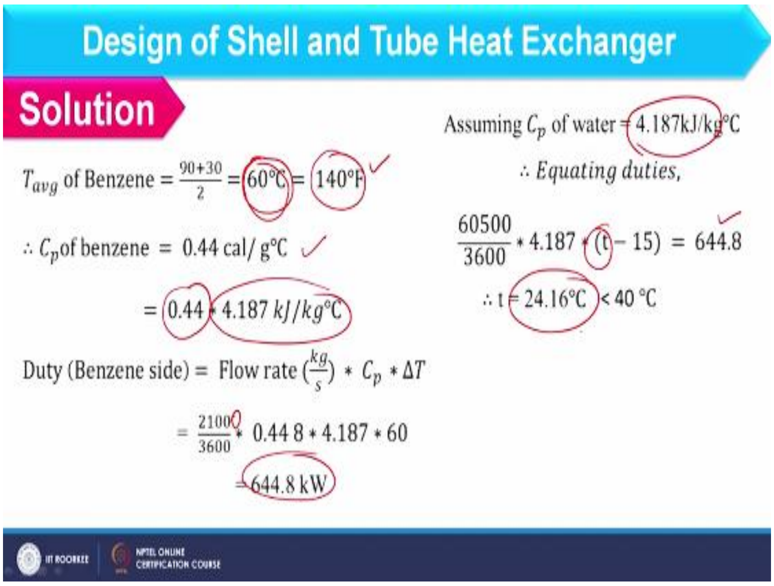

So, if I do that I will find average temperature as 60 degree Celsius and when I convert it, it comes as 140 degree Fahrenheit. So, at this particular temperature you have to find out the C p value from the property data and if you remember we have property data like this and if I am considering benzene considering to benzene the number is 23 so if you see here I am having this.

So here you see I am having this 23 dot and 140 is the average temperature, so if I consider this 140 will lie here. So, if I join this line it will cut this right axis and the value we can obtain for benzene as equal to 0.44. If you draw the line properly it will come at 0.44. So, once I am having this specific heat which is available in calorie per gram degree Celsius so that I can convert into the required unit.

And we can make the balance here we should have 21,000 and total heat duty comes as 644.8 kilowatt. So, you can find out the heat duty accordingly and the same heat duty should be available for water also. So, I can calculate the second temperature which is unknown to us for water. So, just make the balance of mCpdT. Now to make the balance we should also know the specific heat of water.

In the case of water you can make the assumption of C p value as 4.187 because that value is known to us otherwise whatever value of C p we assume based on that we have to find out the unknown temperature and then I can do averaging of both temperature of second fluid which is water in this case and at that average temperature we can see the specific heat value from the data or from the graph.

So, at average temperature whatever C p I will obtain from the graph should be equal to the assumed value. If it is not we have to take the value of C p which we have seen from the graph and then again we have to calculate the unknown temperature of the stream, we have to make the balance and we have to do the averaging and at that average temperature again I have to find out value of C p from the graph.

So, this is basically iterative method, but that method can be avoided when I am considering water. So, let us see the heat balancing over water. So, here I have assumed C p value of water as 4.187 and total heat duty available to me is 644.8 kilowatt so I can find out the unknown temperature which comes as 24.16. So, here you have to check this temperature and that checking should be done only in the case of water because what will happen when I am considering the water at this exit temperature water will enter into the cooling tower.

And from cooling tower it gets cooled down and then it returns back to the exchanger. So that cycle is going on so in that case we ensure that exit temperature of water should be less than or equal to 40 degree Celsius and the reason behind this is that because at high temperature solubility of component in water decreases and that decrement starts beyond 40 degree Celsius.

So, when that solubility decreases precipitation will increase and material will start depositing over the surface. So, it may create problem for cooling tower. So, here you have to check that exit temperature of water should be less than equal to 40. Now, if it is coming more than equal to 40 now if this temperature comes more than 40 degree Celsius we have to revise the flow rate of the water because temperature we have to be very carefully chosen. So, this check you have to do over here which we find correct in this particular case.

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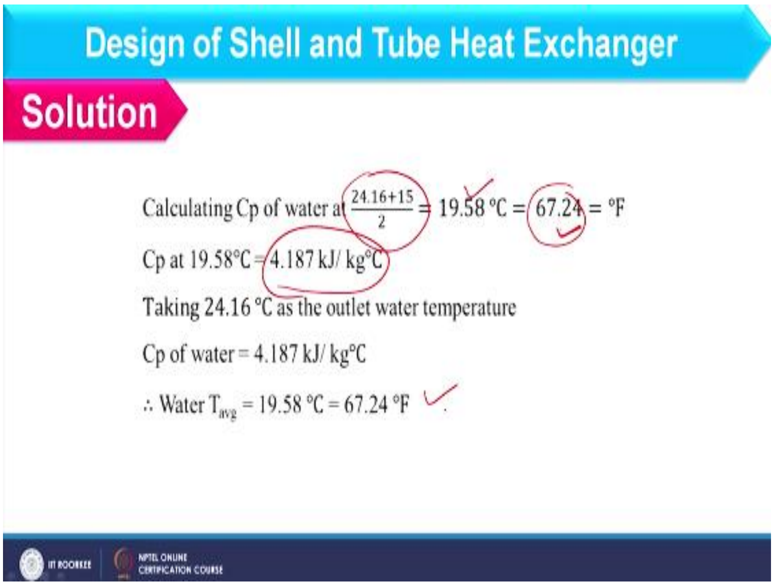

And then we carry out the averaging of the water which is coming as 19.58 degree Celsius and that should be 67.24 degree Fahrenheit. Now at this average temperature, we again have to see the C p value from the graph which will come out as 4.187 so in the case of water the assumption will be equal. However, that will be completely iterative approach when you are considering the other fluids than the water and there is no guideline to assume initial C p value that randomly you have to assume.

So, we can consider that average temperature of water should be 67.24 degree Fahrenheit. So, we know all temperature of both fluids.

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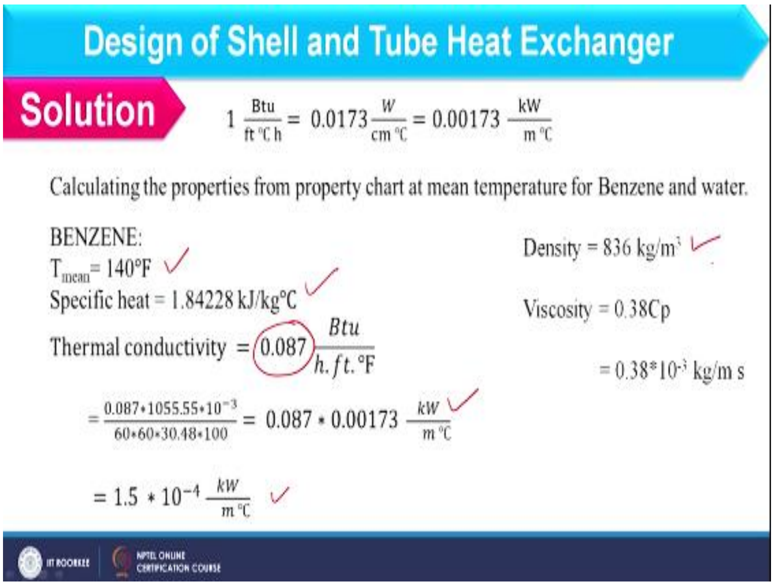

So, next step is we have to collect other properties because I know the average temperature of both fluids. For benzene the average temperature is 140 degree Fahrenheit C p value we have already obtained. Thermal conductivity we can see from this table. So, if you see here I am having the benzene and corresponding to 140 degree Fahrenheit we can have value as 0.87. So that 0.87 we have considered and then converting it into the desired unit we can find out thermal conductivity of benzene as 1.5 into 10 to the power – 4 kilowatt per meter degree Celsius. Density of benzene that we can obtain and similarly we can obtain the viscosity of benzene.

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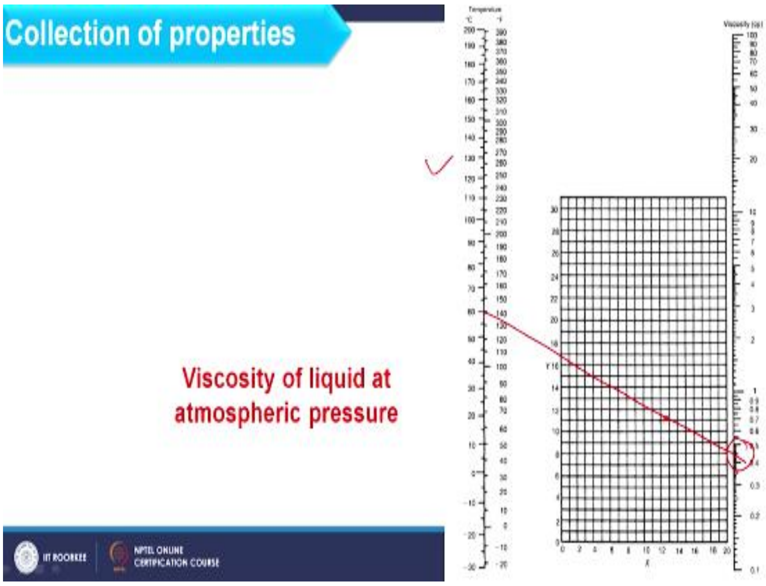

So for viscosity we can use this graph and X, Y value as we have already explained that you can take from here and for benzene it is 12.5 and 10.9. So you can simply make the point over here, so it will lie somewhere here 140 degree you already know the average temperature so we can make the line joining this point and somewhere it will cut the right axis and similarly we can find out value of viscosity of benzene as 0.38 centipoise.

So it should be centipoise. So, when I convert it I can find 0.38 into 10 to the power – 3 kg per meter second that is basically the desired unit to carry out the calculation.

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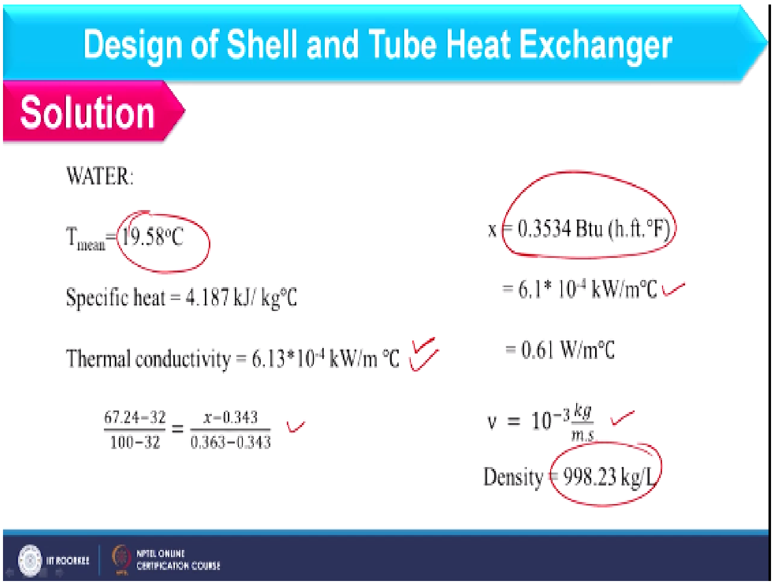

In the similar line, I can find out the thermal conductivity of water. So, you can see average temperature is 19.58 which can be converted into Fahrenheit and thermal conductivity we can obtain by this and thermal conductivity of the water we can find as 6.13 into 10 to the power – 4. Now how I will obtain that? Let us see the thermal conductivity table. So, this is the table where for water I am having complete range of temperatures and accordingly thermal conductivity is given.

So my value will lie in between these two because it is 67 degree Fahrenheit. So in between this the value will lie and you can interpolate between these two values. So, here I have interpolated and find the X value as 0.3534. When we convert this, we can find thermal conductivity as this as it is shown over here also. Viscosity of the water you know it very well and density of water you can consider as 998.23 which is available at average temperature.

Otherwise as a rough estimate you can consider 1,000 kg per meter cube as density of water. So here at average temperature we have found all properties of both streams. So, next is we have to find out the log mean temperature difference because I know both temperatures of both fluids. So, how I will do the LMTD calculation considering counter current flow.

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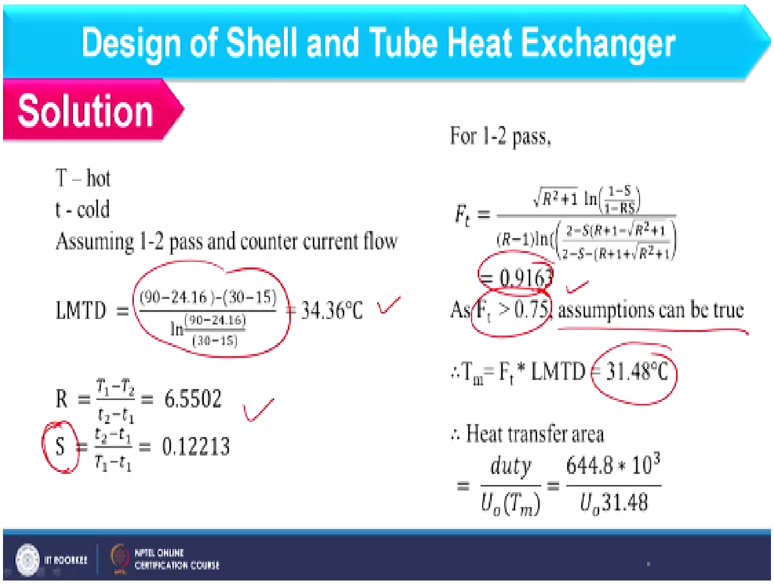

So, simple LMTD expression you know so that we will apply over here and 34.36 degree Celsius we have obtained. So, as it is the LMTD for counter current flow we have to carry out shell and tube heat exchanger design where at least one, two pass I should consider. So in that case F t correction factor should also be included. So, for that purpose we have to find out R and P value.

And in some books instead of P we can also use S so values of R and S are given like this and we can find out F t correction factor as 0.9163. Here you should check that F t correction factor should be more than 0.75 so this assumption is valid over here. Now the point is if it comes less than 0.75 so what we have to do? We have to increase the shell pass. So, instead of 1-2 shell and tube heat exchanger we should consider 2-4 passes in shell and tube heat exchanger, but here in this case we are in a safer side so we will proceed with the same value.

So, if I calculate true LMTD I can obtain its value as 31.48 degree Celsius and next step is to find out heat transfer area and for area we have to assume overall heat transfer coefficient value.

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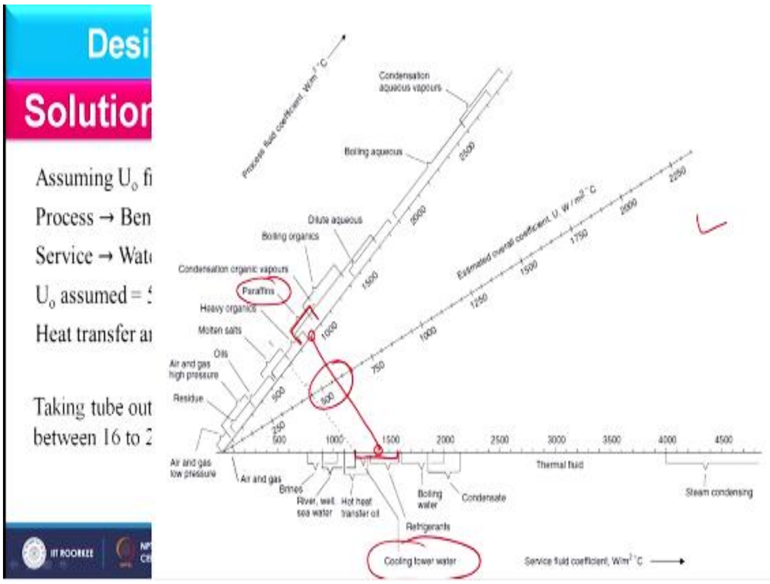

So that assumption you can take using this graph. So we have benzene as well as cooling tower water. So, cooling tower water range is available from this to this. So, you have to consider the middle point of this complete range and for process fluid we have benzene and that we can consider for paraffin though it is not the paraffin, but we are considering this range because you do not know in which category it will fall.

So, we are considering paraffin over here so the complete range is this you can consider middle point over here and then you can join these two points with the straight line so the value will come around 575 so that you can take as initial guess.

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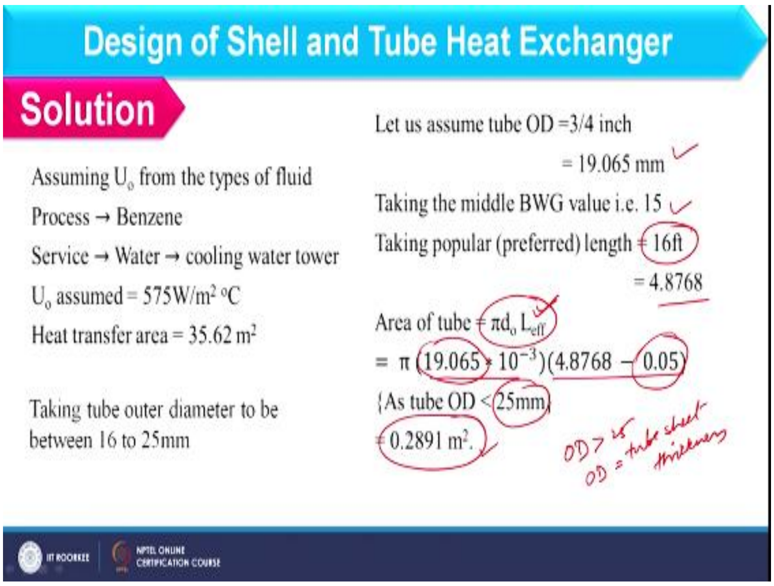

So, the value of overall heat transfer coefficient you can obtain 575 as initial guess so heat transfer area you can calculate as 35.62 meter square. Now we have to decide the tube dimensions if you remember the diameter of the tube the optimum diameter varies from 16 mm to 25 mm that point we have already discussed in a lecture where we have discussed tubes.

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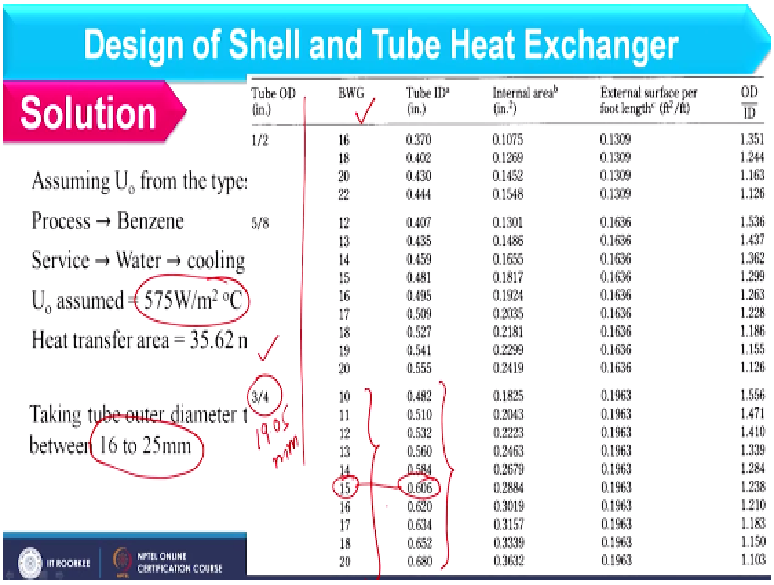

So, we will see the data for tube dimension. So if you see here I am having the table and this 3 / 4 will lie between 16 to 25 mm. So, if I convert we can find the value as 19.05 mm so that will lie between 16 to 25 mm. So, we should choose OD as 3 / 4 and how I should choose ID of the tube that I can do while selecting correct BWG value and correct BWG value you can obtain from middle of this complete range.

So, I am taking 15 BWG value and corresponding to this internal diameter of the tube becomes 0.606 inches. So, OD of the tube we can obtain 19.065 and BWG value we have consider as 15. So, how I will choose the tube length if you remember the tube length which are available in standards these are 6, 8, 12, 16, 20 and 24 feet. So, we will consider the middle value of this.

So for calculation purpose I am choosing 16 feet as the tube length which we will convert it to meter and it comes as 4.8768 so that is the dimension of tube we have to verify these dimension later on. So, next point is we have to consider the area of a single tube. So, area of single tube we can find by this pi d 0 L effective why I am considering L effective that I have also discussed previously that some section of the tube is inside the tube sheet.

And that section will not participate in heat transfer. So, from the total length we have to deduct the thickness of tube sheet into two because for each tube I am having two tube sheets. However, if I am considering U tube or so we can have tube sheet only at one side not the other side, but in this tube sheet U tube will enter twice. First is above and second is below. So, in that case again you have to deduct twice into tube sheet thickness from the total length of the U tube.

So considering pi d 0 and L effective we can calculate area of single tube as 0.2891 meter square. Now, how I am considering this 50 because OD of the tube is less than 25. So tube sheet thickness should be at least 25. If OD of the tube is more than 25 then the OD of the tube will be equal to tube sheet thickness. So, in this way we have deducted 50 mm from the total length and we can find out the area of one tube.

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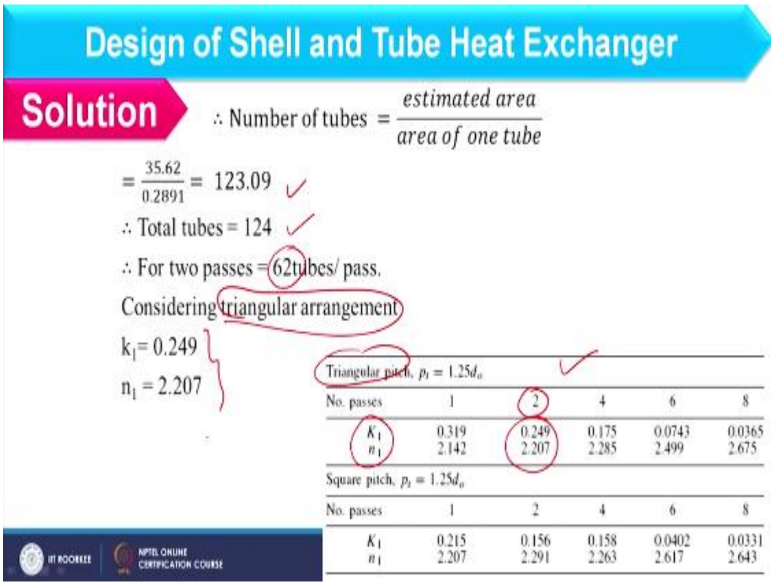

Now once I am having the area of one tube I can simply calculate number of tubes because I already know the heat transfer area. So, the calculation gives 123.09. As I am having 1-2 pass the tube number should be even. So I am considering 124 as total number of tubes, two passes I am considering so 62 tubes will be available in one pass. So considering the two pass and assuming triangular arrangement.

As we have already discussed that triangle and a square pitch are used extensively. So here I am considering triangular arrangement. So, you have to refer this table to find out bundle diameter because bundle diameter needs the value of K 1 and n 1. So, I am having two pass and triangular pitch. So K 1 and n 1 value you can consider like this which are also shown over here.

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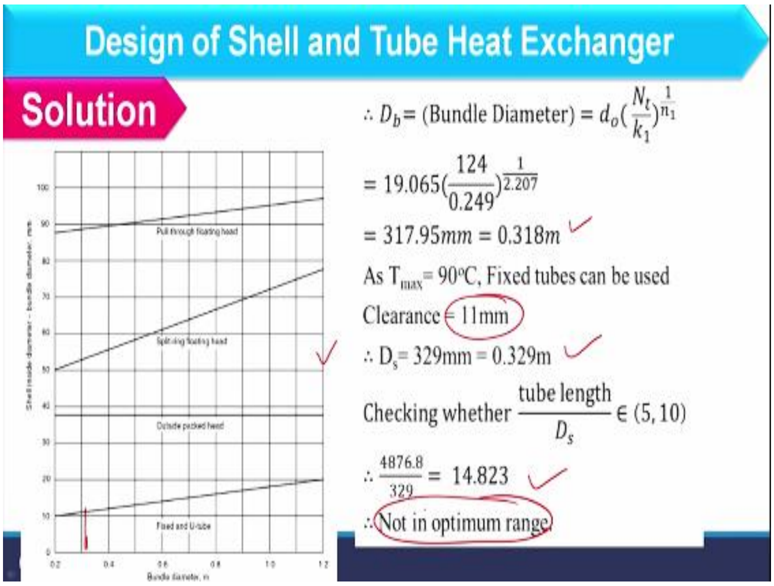

So, if I am having K 1 and n 1 value I can find out the bundle diameter considering d 0 of the tube and that calculation gives bundle diameter as 0.318 meter. Now, next you have to find out the clearance how should find out the clearance using this graph and in this graph we have to choose the right exchanger. How I can choose that? I have told you that if maximum temperature in exchanger is equal to or less than 90 degree Celsius we should choose fixed tube sheet because that is the simplest and cheapest also.

So in that case if I use this graph so 0.317 or we can consider as 0.318 so it will lie somewhere here. So, the value comes as 11 mm as a clearance so I can find out shell diameter. Now once you have length of the tube it is basically the length of shell also and the shell diameter. So, we have to find out L / D ratio. So, if you consider that length / D s value the ratio comes as 14.823 which is not in the optimum range.

Optimum range is from 5 to 10. So, what I have to do over here because my ratio is coming very larger in comparison to the desired value. So in that case instead of changing shell dia I will change the length of the tube. So, how I can choose the next length because I have to reduce this ratio so I have to reduce the length. So, the length below 16 feet available in the literature or available in the standard and that length is 12 feet.

So we have to carry out the calculation considering 12 feet. So, where I should start with? If you consider the length of the tube it is first used in tube number calculation so we have to again find out area of one tube and then the number of tube and then bundle dia then shell dia and then L / D ratio.

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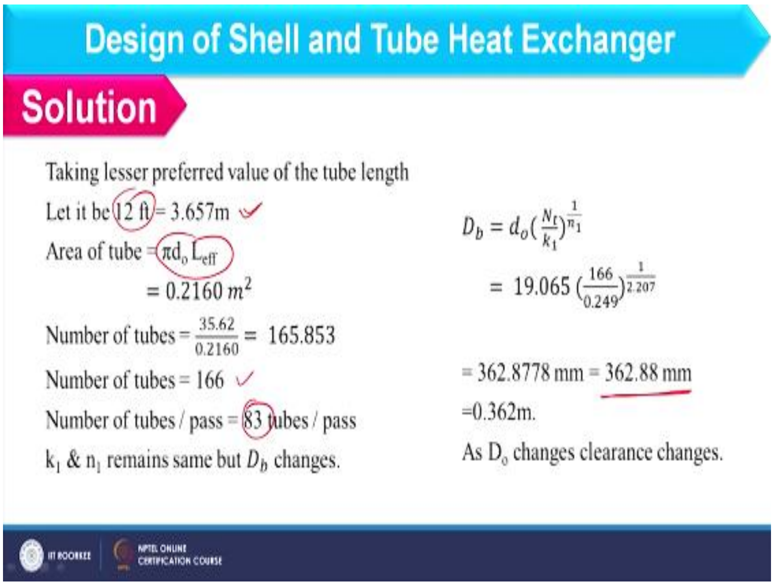

So, here I am considering L effective based on 12 feet meter length which will be equal to 3.657 meter. In this case number of tubes will be 166 because I have to consider even number so 83 tubes will fall in each pass. So, accordingly I can calculate bundle dia.

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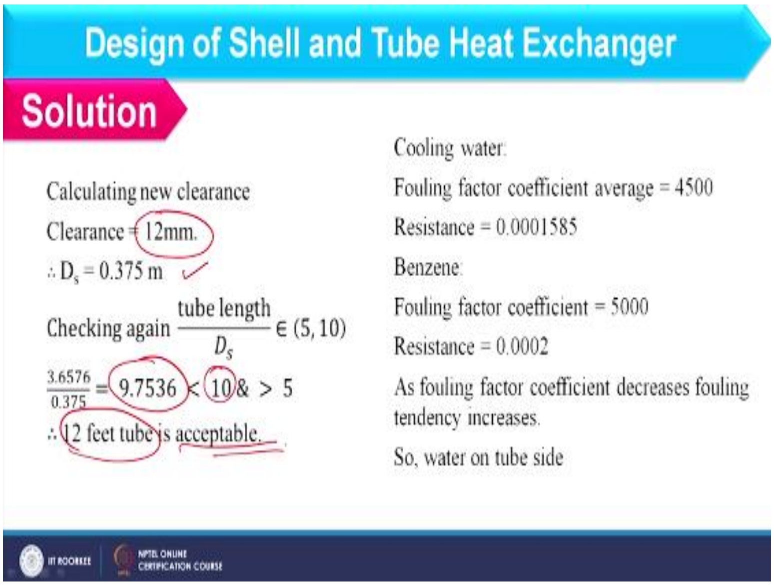

Considering clearance from the same manner as we have discussed in the last iteration. Diameter of shell is equal to 0.375 and L / D ratio will come as 9.7536 so that should be less than 10 so we can consider that 12 feet tube length is acceptable. So, in this way you have decided the tube as well as exchanger length and tube diameter and the shell diameter. So, further what we have to do we have to allocate the fluid to shell side or tube side.

So, now if I ask you which fluid has more tendency of fouling because based on corrosion, based on fouling we have to locate the fluid. So, if I consider the fouling factor of water as well as benzene you should use this table.

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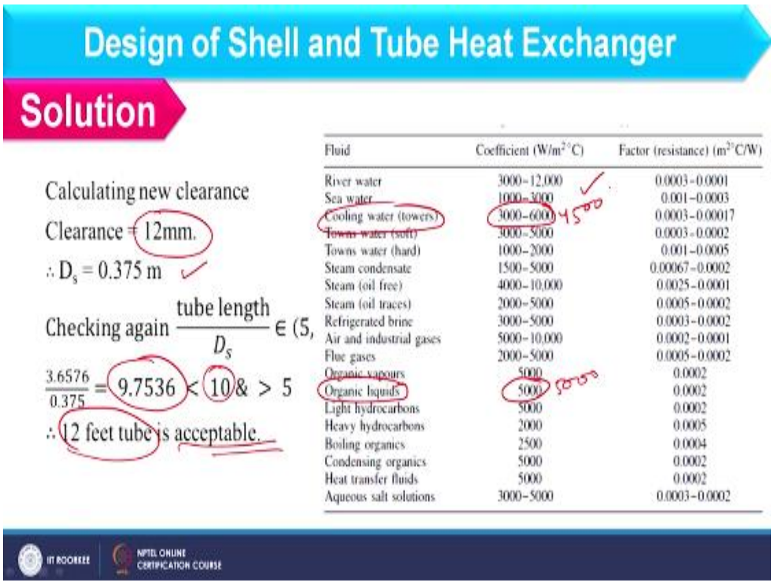

So in this table we can consider organic liquid and benzene will fall in this category. So we have coefficient as 5,000 for benzene cooling tower water the range is given as 3,000 to 6,000 so we have to take the average length so here we can have the value 4,500 and 5,000 for benzene. So, if you see heat transfer coefficient is less for water it means dirt factor is more for water. So, water should be allocated to tube side and benzene is allocated to shell side.

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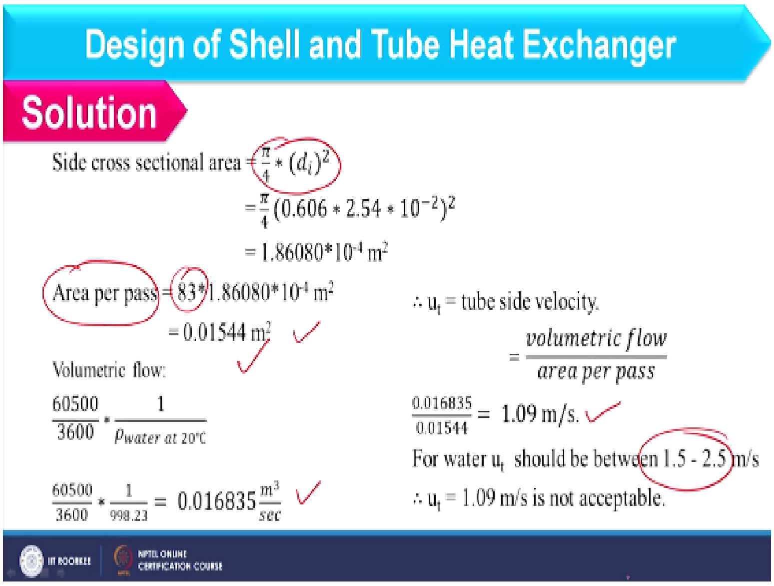

Now, if you have allocated the fluid to shell side and tube side you have to find out heat transfer coefficient of tube side as well as shell side. So, first of all we will calculate that for tube side and to carry out that we have to find out the velocity and for velocity I have to choose cross-sectional area of single pass. So for that we can consider cross sectional area of a single tube.

I know the number of tube so I can find out area per pass as it is shown over here and the value comes as 0.01544 and considering the volumetric flow and this area we can find out velocity of water as 1.09 meter per second. So, if you see it is not falling in the range and the range is like 1.5 to 2.5 meter per second. So we have to increase the velocity for that purpose what I should do?

We have already discussed this in last lecture that if velocity is not falling in the range we have to increase the passes and the purpose of passes is to maintain the right velocity. So, instead of 1-2 I will consider 1-4 pass.

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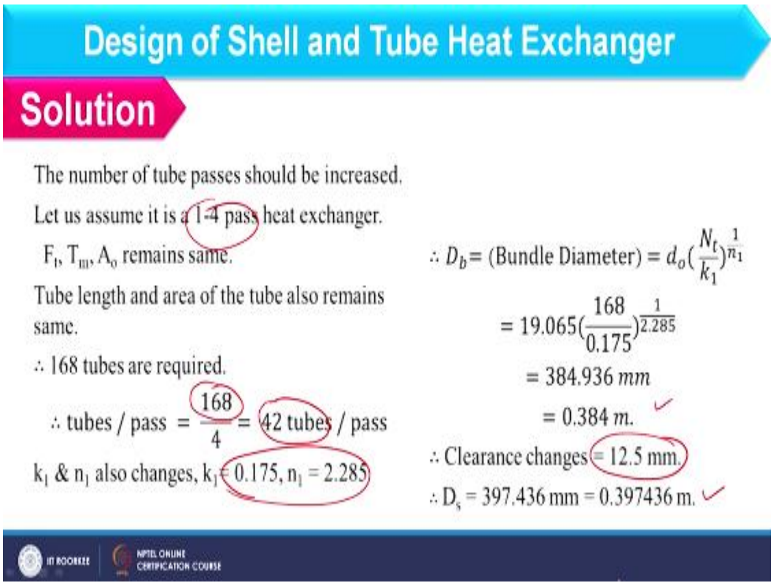

For 1-4 pass what change I have to do? So 1-4 pass what changes we have to carry out? First change is when I am considering the bundle dia because for 1-4 pass k 1 and n 1 value will change and once I am having this we should also find out the correct tube numbers. Though, I have already find out as 166 in 1-2 pass now for 1-4 pass if you divide 166 / 4 the value will come in decimal so that is not acceptable for tube.

So, we will increase the number of tube which should be completely divisible by 4. So that value I am considering as 168 so 42 tubes will be allocate to one pass. So, k 1 n 1 value you can find as we have done previously and corresponding to that bundle diameter we can obtain as 0.384 meter considering the clearance we can consider shell dia as 0.3974 meter. So, in this way you can revise the calculation based on new assumption.

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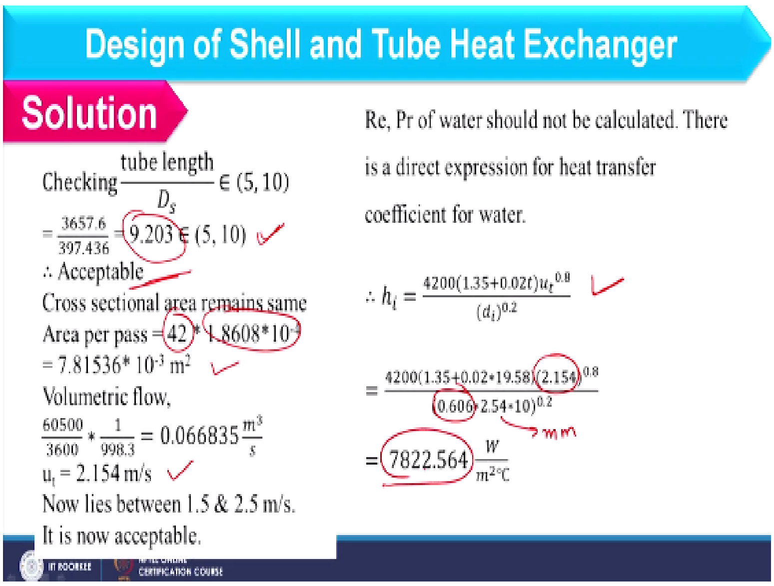

So, once I am having this shell dia we can again check L / D ratio every time we have to do this because we should also ensure that optimum ratio should be obtained. So if I am doing so I am finding L / D ratio as 9.203 which is in the range and so the length and diameter is acceptable. So, next is we have to find out the right velocity and for that we have to calculate area per pass.

So, considering 42 tubes and cross sectional area of single tube you can find the area per pass. Considering the volumetric flow as well as area per pass you can find out velocity as 2.154 meter per second so it is in the range. So, we can choose this velocity for further calculation. Now, if you remember for heat transfer coefficient of water we have a specific correlation. So, instead of going to generalize equation we can use this equation which is given for water only.

So, considering all these value like velocity over here and this is the d i inner diameter which we have already discussed. So that value I should keep in mm. So considering this value heat transfer coefficient of tube side we can obtain as 7822.564 watt per meter square degree Celsius.

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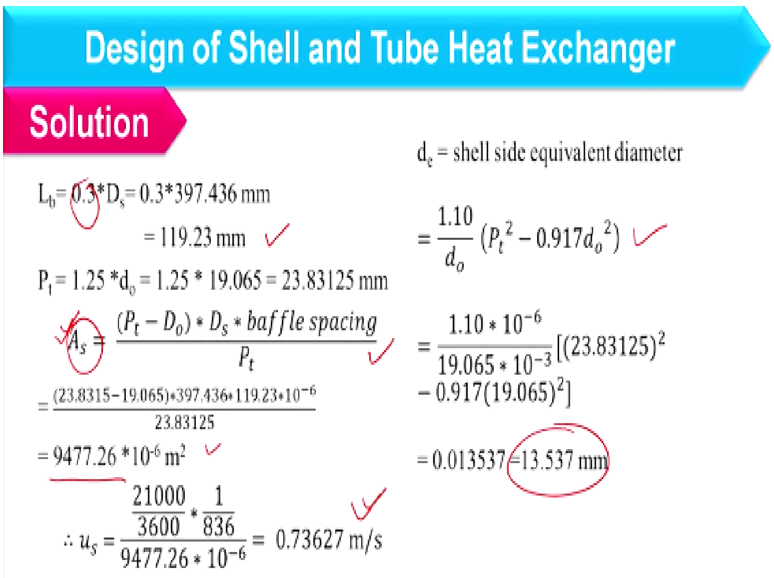

Now, next step is what? Next step is to find out heat transfer coefficient in shell side and to carry out this we have to specify baffle spacing. So, the baffle spacing if you remember the optimum range varies from 0.3 to 0.5 into shell dia. So, here I am considering 0.3 into shell dia. So, baffle spacing comes as 119.23 and here I am considering Kern's method for heat transfer coefficient calculation in shell side as well as pressure drop in shell side.

In that case first of all I have to find out the cross sectional area at bundle equator. So that is basically the assumption of Kern's method. So, considering this we can find out cross sectional area in shell side as this is basically not cross sectional area this is cross flow area. So this P t – D 0 into D s into baffle spacing this expression we have already discussed and A s value we can obtain as 9.477 into 10 to the power – 3 meter square.

Considering this we can find out the velocity in shell side. So, if you remember the range of velocity in shell side that should be 0.321. So this velocity is falling within the range and next we have to find out the equivalent diameter in shell side. So, we can use the equation for triangular pitch and equivalent dia we can obtain as 13.537 mm.

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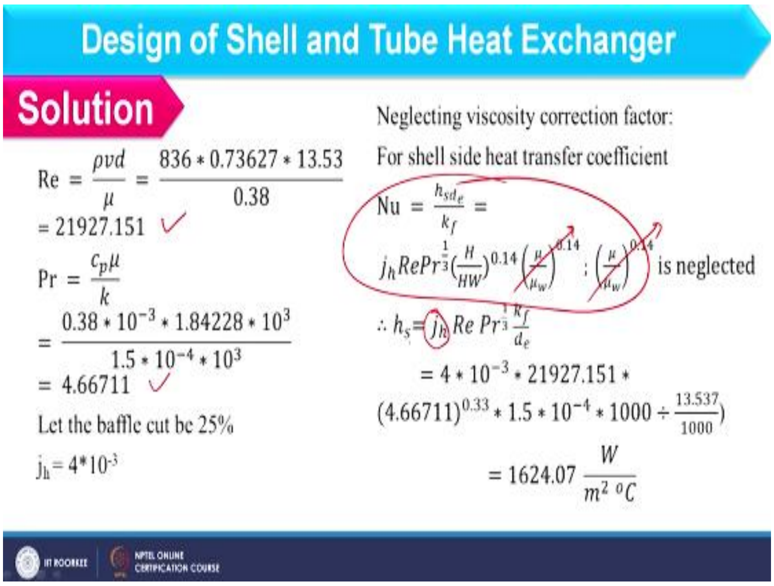

So, considering all these value we will find out the Reynolds number and then the Prandtl number and then we will consider the heat transfer coefficient expression and which is basically this for shell side. So, here I am neglecting this term that is the viscosity correction factor so this I should not consider and here we have to find out j h value.

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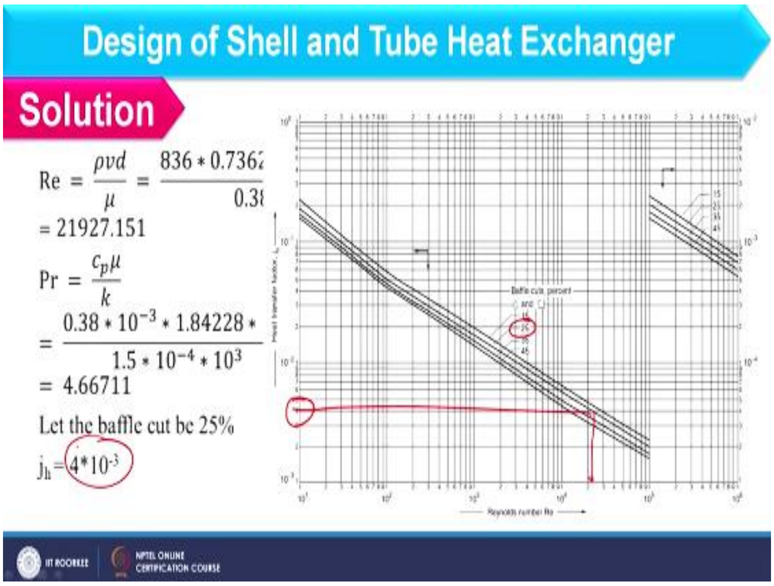

So for that you can use this graph so the Reynolds number is coming as 2.2 so that will be equal to here and if you consider baffle cut, baffle cut I will consider as 25 because it varies from 15 to 25 in optimum range. So for this value we can consider the graph and you can obtain the value of j h as 4 into 10 to the power – 3 which you can write here to find out heat transfer coefficient in shell side and which comes as 1624.07. So, here I am having heat transfer coefficient in shell side as well as in tube side.

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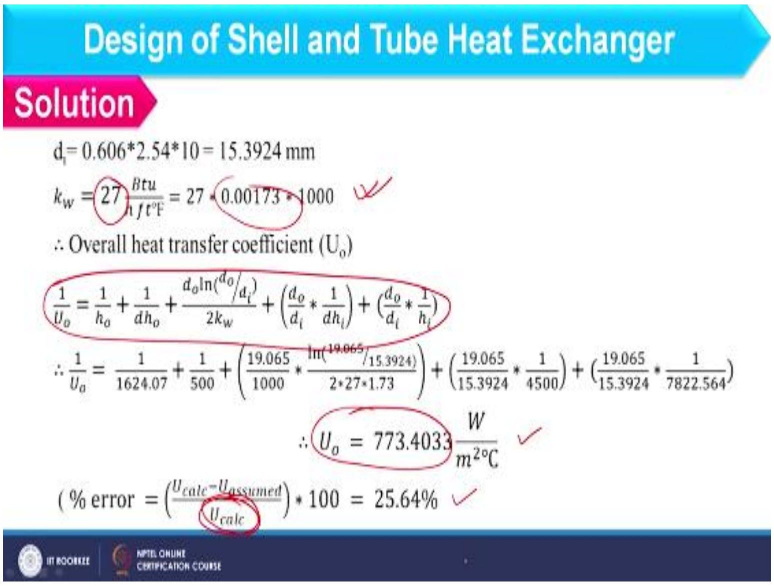

So I can calculate overall heat transfer coefficient because you know dirt factor of both fluids and you also know the thermal conductivity of the material. So that thermal conductivity you can assume as 27 and when I convert it I can find the thermal conductivity like this and you put all the values in this expression and overall heat transfer coefficient you can find as 773.4. I should compare that with assumed value should come.

So, if I consider that the percent error I am finding as 25.64. Now, if it is also possible that based on assumed value the error in U value should be more than 30%. In that case you have to consider revised value of U 0 as 773.4 and you have to take the revision from area calculation. So in that way you have to calculate overall heat transfer coefficient. Now, we will proceed for pressure drop in tube side as well as shell side.

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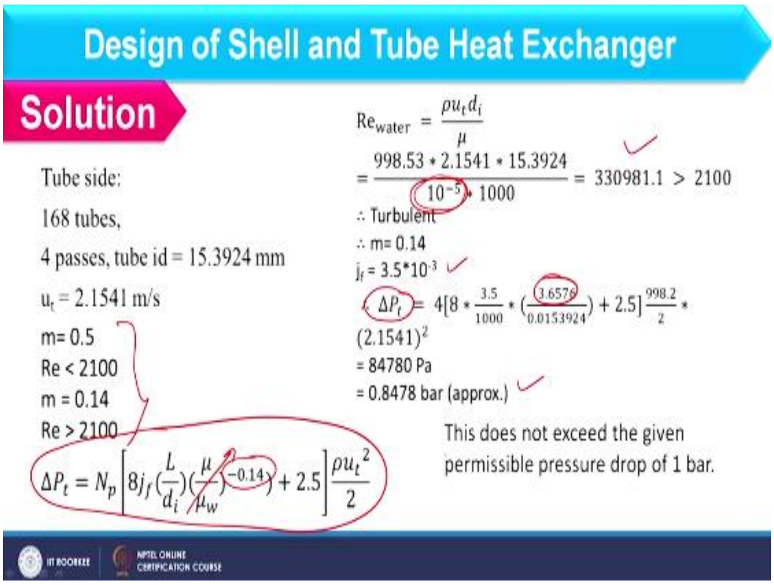

So this is the expression to find out pressure drop in tube side where I am neglecting this term viscosity correction factor and if you consider this 0.14. So, this is the criteria if Reynolds number is more than 2,100 we have to choose m as – 0.14. So, Reynolds number you can find as this value 3.3 into 10 to the power 5 so that is more than 21,000 so we can consider turbulent flow, but because I am not using viscosity correction factor this calculation is not required, but if it is required you can choose accordingly.

So now you have to find out j f also for pressure drop in tube side and that you can find through this graph. So, if you see the Reynolds number you can obtain as 3.3 j f value you can find as 3.5 into 10 to the power -3. So, we can consider pressure drop calculation further considering the total length of the tube because we have already discussed that total tube length will give the pressure drop because total tube length will have the friction.

So, we can find out pressure drop in tube side considering total length and the value comes as 0.8478 bar which is less than 1 bar. So condition is satisfied over here.

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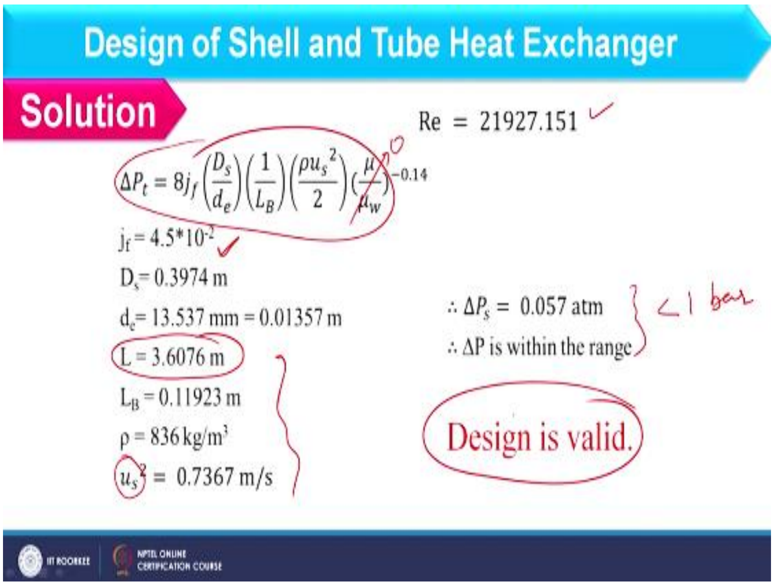

Next, we will consider the pressure drop in shell side for that you have to use this expression considering neglecting viscosity correction factor and for this Reynolds number which we have already calculated to 2.2 somewhere here and this is 25 baffle cut. So, you can find out the value of j f at this point which will be around 0.5 into 10 to the power – 2 which will be around 4.5 10 to the power – 2.

And here you should consider effective length because shell side whatever length is available in tube sheet it will not give any pressure drop or any friction. So considering all these values you can calculate the pressure drop and here it is u s not u s square and pressure drop you can obtain as 0.57 atmosphere or you can convert that into bar and that will be less than 1 bar. So, in both side pressure drop is within the limit.

So, we can say that design is valid. So in this way you can design shell and tube heat exchanger it is the detailed calculation and it is really time-consuming to design a shell and tube heat exchanger with each detail.

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1	Backhurst, J.R. and Harker J.H., "Coulson and Richardson Chemical Engineering", Vol. II, 5th Ed., 2002, Butterworth-Heinemann.
2	Sinnott, R.K., "Coulson and Richardson's Chemical Engineering Series: Chemical Engineering Design", Vol. VI, 4th Ed., 2005, Elsevier Butterworth-Heinemann.
3	Serth, R.W., "Process Heat Transfer: Principles and Applications" 2007, Elsevier Ltd.
4	Shah, R.K. and Sekulic, D.P., "Fundamentals of heat Exchanger Design", 2003, John Wiley & Sons.

So, here we are having some references you can go through the problems given in this book for design of shell and tube heat exchanger using Kern's method.

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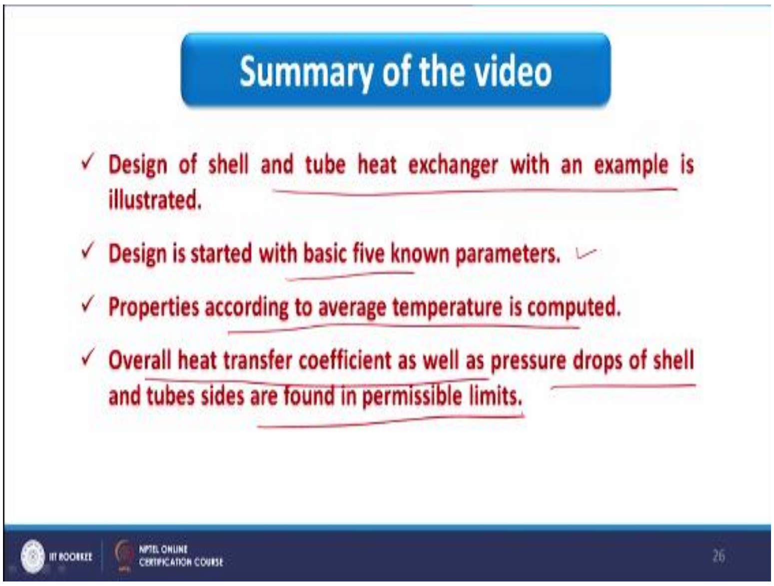

And now I am having the summary of this video and here design of shell and tube heat exchanger is illustrated with the help of one example. Design we have started with basic five known parameters that I have already discussed. Properties according to average temperature is computed and I have already explained how you can obtain these properties and finally overall heat transfer coefficient as well as pressure drop of shell and tube side are found in permissible limit.

So in that way you can complete the design of shell and tube heat exchanger here you should consider one point that error in overall heat transfer coefficient I am considering based on assumed U 0 value the error may come more than 30%. So, there you have to repeat the complete calculation from area step. So, I hope things are clear to you and that is all for now. Thank you.