Process Equipment Design
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Lecture –13
STE Design- Kern's Method-2

Hello everyone. Welcome to the 13th lecture of the course Process Equipment Design. Here we are in third week of this course. If you remember the last lecture, we have started design of shell and tube heat exchanger using Kern's methods. So, we have discussed of two shell diameter calculation in that lecture and after that we are going to cover the design part in this lecture. So, let us start this.

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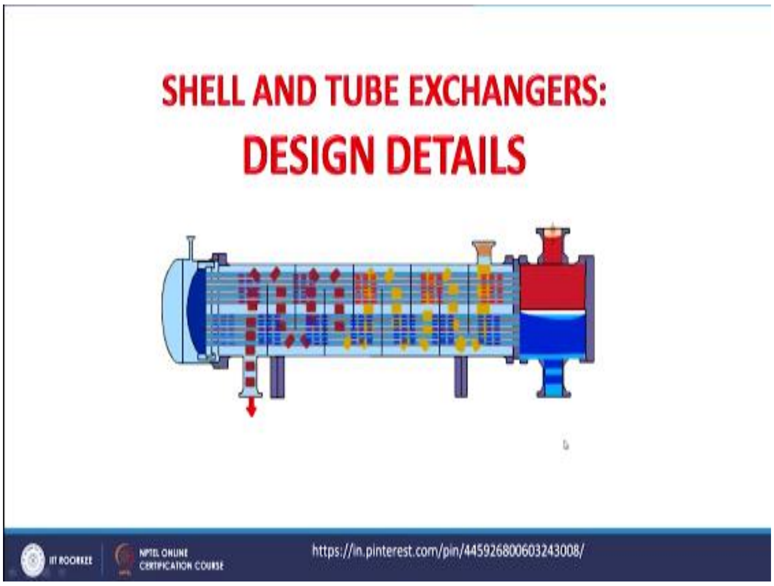

Here, we have the design details which we have started from the last lecture and if you want to study this in detail this animation you can find and if you want to study about this animation or details about this you can find from this website. So, let us start the procedure of two shell diameter calculations we have already covered in the last lecture and after that next step is to estimate tube side heat transfer coefficient because once I have decided the tube diameter I have decided the arrangement, the bundle diameter and shell diameter.

So, we have all geometry available so that we can calculate overall heat transfer coefficient and for that we have to estimate tube side as well as shell side heat transfer coefficient. So, let us start with tube side heat transfer coefficient.

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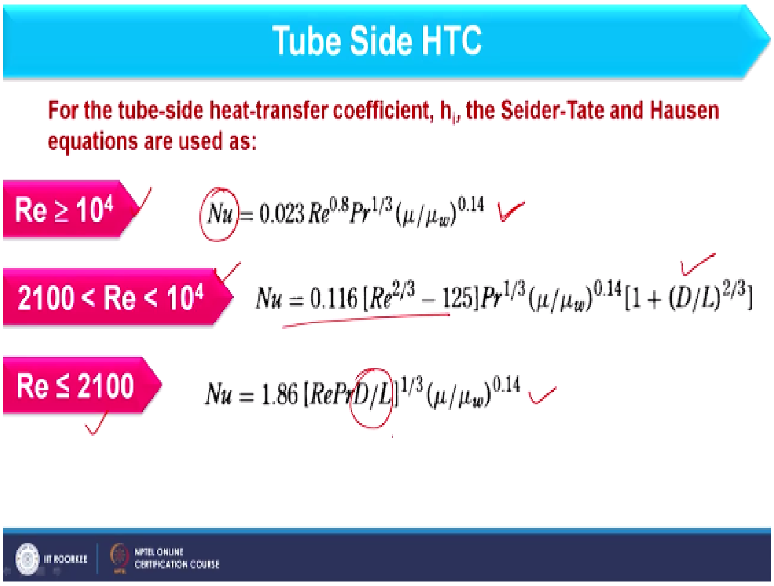

Now if you see the tube side heat transfer coefficient how this tubes look like. These tubes are basically straight pipe. So, here you can use the usual expressions available to calculate heat transfer coefficient in the pipe or inside the straight tube. For that we have Seider Tate equation and Hausen equation. So, it will depend on the Reynolds number. If Reynolds number exceeds 10 to the power 4 or 10,000 you can use this equation to calculate the heat transfer coefficient in tube side.

And here this Nusselt numberis basically (()) (03:08) and thermal conductivity of the fluid you have already collected in physical property collection step. So, if I am having the transition zone where Reynolds number varies from 2,100 to 10,000 there you can use this Hausen equation where it will depend on diameter as well as length and if Reynolds number is less than 2,100 means it is falling in laminar zone.

Then you can calculate the heat transfer coefficient using this expression which is basically Seider Tate equation where in laminar zone the heat transfer coefficient depends on D / L ratio.

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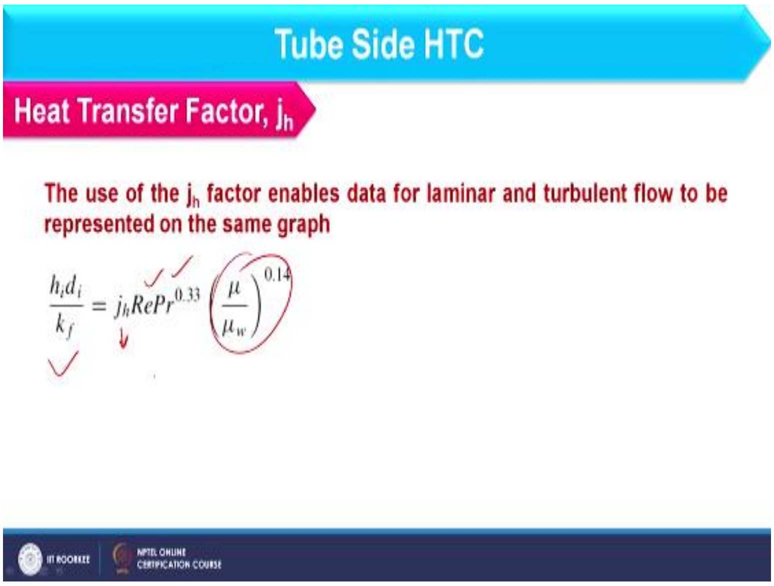

So what we have seen till now? We have seen that depending upon the Reynolds number we can have different expressions which we can use to calculate tube side heat transfer coefficient. Apart from this, I am having one general expression also which you can use to calculate heat transfer coefficient irrespective of the type of flow. Before you have to calculate Reynolds number, you have to find out the region and accordingly you have to choose the equation.

However, this expression where I am having this Nusselt number hi di / kf is a function of Reynolds number and Prandtl number and here we have this viscosity correction factor. So this is the general expression where we have used j h which is the heat transfer factor so that j f factor depends upon laminar and turbulent zone and that you can compute from the same graph.

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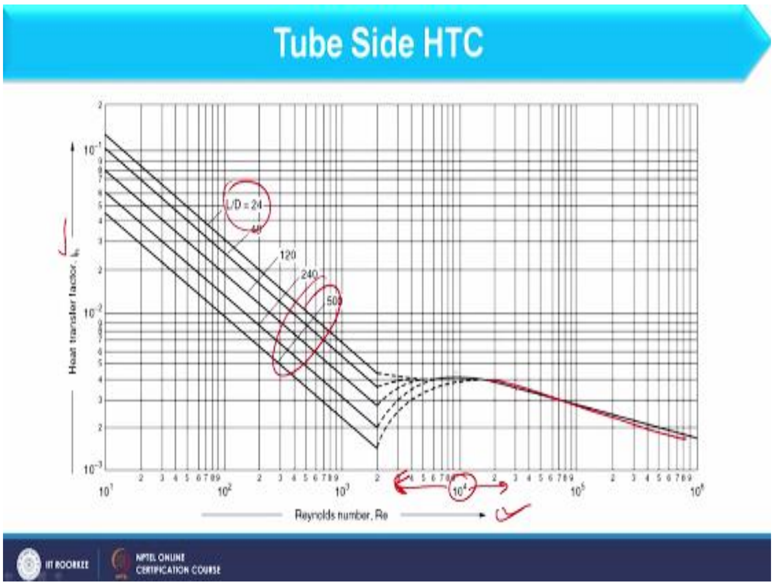

So, this is the graph which you can use to find out heat transfer factor j f according to the Reynolds number. So, Reynolds number you have to calculate anyhow, but you should not choose the equation depending upon the Reynolds number you can directly use this graph. Now if you see this is basically 10 raise to the power 4 so beyond that we have turbulent zone and below that we have transition zone as well as laminar zone.

So in both zone you can have different curves and in turbulent zone we have only one curve here we have different curve depending upon L / D ratio. So, if you correlate this with a given equation that is Seider Tate equation and Hausen equation for laminar as well as transition flow there L / D was also there so that you can relate with this curve only. So, you can directly use this curve to find out j f and then you can find out tube side heat transfer coefficient.

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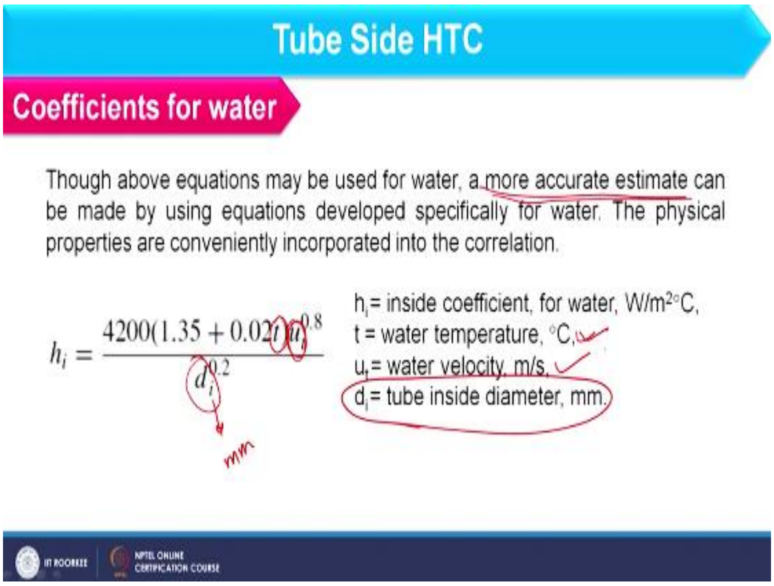

Till now whatever expressions we have used that is based on the fluid. Fluid means whatever fluid you are considering you can calculate heat transfer coefficient in tube side using previous expressions, but here I am showing another correlation which is specifically given for the water. So, however it does not mean that for water you cannot use the previous equation you can.

But this is more accurate expression so it is expected that for water you should use this expression. So it gives more accurate prediction of heat transfer coefficient when water is flowing inside the tube and here it will not depend on the physical properties. Whatever velocity of water you can estimate d i is the initial diameter of the pipe, but this should be in mm.

Actually all these expressions will be known to you it is not like you have to recall or you have to mug up all these equation you have to remember all these equation because in this particular course there are so many graphs and equation that it is very difficult for you to remember all these. So in the exams also these equations will be given to you. So, what you have to do now? You have to understand that how these equation you should apply.

So depending upon the given units only you can find out heat transfer coefficient or other factors. So here usually velocity is available in meter per second, but tube inside dia is given in mm. So, accordingly you have to apply this and this t is basically the water temperature. Which water temperature? This is basically average water temperature because inlet and outlet you have already calculated.

So you can consider the average temperature of water and that you can use over here. So this expression you should use when you are using water as a fluid.

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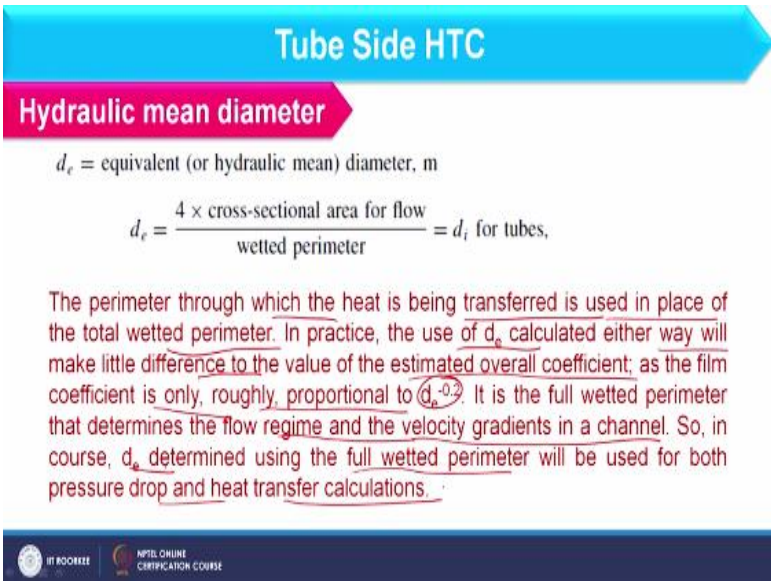

And next we have to find out hydraulic mean diameter because the flow is inside the tube. So inner diameter of the tube will be equal to the equivalent diameter or hydraulic diameter of the tube. So, in this case it is only d i only so why I am considering this? Because the perimeter through which the heat is being transferred is used in place of total wetted perimeter.

So, we consider perimeter of the tube where heat is being transferred. In practice, the use of d e calculate either way will make little difference to the value of estimated overall coefficient as the film coefficient is roughly proportional to de power 0.2. It is the full wetted perimeter that determines flow regime and velocity gradient in a channel. So, instead of considering any perimeter we should consider fully wetted perimeter.

And so in this course also de determine using fully wetted perimeter will be used for both pressure drop as well as heat transfer calculation. So, in this case we are using d i as equivalent diameter because I am considering fully wetted perimeter and next we have the viscosity correction factor. This viscosity correction factor we can use when I am dealing with viscous liquids.

So, usually when the viscosity in two fluids is not different significantly so the values of viscosity of the two fluids are not in much difference we should avoid this correction factor and if I am dealing with viscous liquid we should consider this. So, how I should consider this? This I have already explained in double pipe heat exchanger design where viscosity should be calculated at average temperature of the fluid and at wall temperature.

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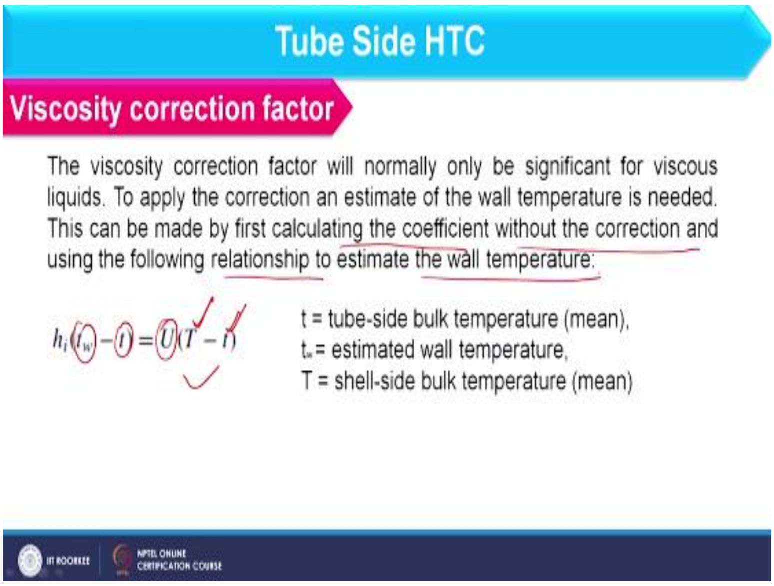

And how you will calculate the wall temperature you can use this expression where I am having this h i that is inside heat transfer coefficient or tube side heat transfer coefficient, tw is the wall temperature and T is basically the tube side bulk temperature or the average temperature and this capital T and small t are either shell and tube side average temperatures, but here everything will depend on this U because here you have assumed value of U.

And once you will calculate this h i you will calculate h o that is the shell side heat transfer coefficient then only you will calculate this U. So, whatever U you will calculate at that point should be in accordance with this U. So, this can be made by first calculating the coefficient without the correction I am using the following relationship to estimate the wall diameter and whatever overall heat transfer coefficient you will calculate if it is not near to that you have to consider that U to find out again tw.

And then you have to consider viscosity correction factor accordingly. So, here it should be again the trial and error method, but that should be considered when you are dealing with viscous fluids not the normal fluids.

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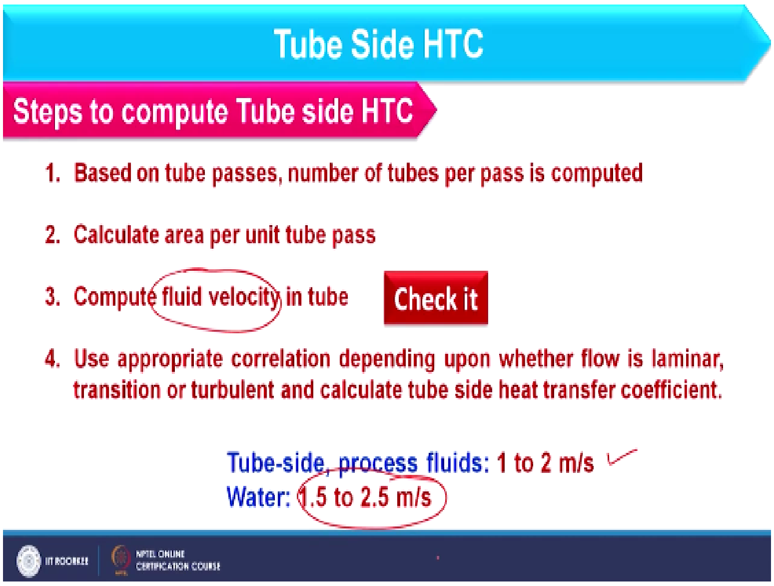

Now here we will consider different steps which are used to find out tube side heat transfer coefficient. The first step is based on the tube passes number of tubes per pass is computed because you already know the number of tubes, you have already decided the passes so you can find out how many tubes are falling in single pass and then you have to find out the cross sectional area per pass.

How you can find out that because you know that cross sectional of tube is pi / 4 di square. So that should be multiplied by number of tubes per pass. So pi / 4 di square into number of tubes per pass will give the total area or we can say the total flow area per unit pass and after that you will find the tube velocity because area per pass you have already calculated and you already know the mass flow rate of the fluids.

So considering the density you can calculate volumetric flow that should be divided by area per pass to give the velocity of that fluid in tube side. Now once you have that you have to check it. What you have to check it? Just recall the lecture where we have discussed basic design parameters and there we have discussed the limits of velocities as well as pressure drop.

So, here you have to match with this like tube side process fluid should have the velocity like 1 to 2 meter per second. So, whatever velocity you will obtain over here if it is for process fluid it should be within 1 to 2 meter per second and if it is for water it should lie from 1.5 to 2.5 meter per second so in that way you can check that velocity is falling within the range or not and if it is not falling you have to increase the pass.

And if it is not falling it means if it is falling less than the minimum value of this range you should increase the pass otherwise you should decrease the pass or if some small changes are required that can be done through the change in tube dimension, but the point is whatever you are changing just keep in mind whatever you are changing, what previous parameters are changing that also you should keep in mind.

To give an example if you are changing the diameter of the tube in that case number of the tubes, bundle diameter, shell diameter, L / D ratio, heat transfer coefficient of tube side everything will change. However, when you are changing the passes then bundle diameter, shell diameter, L / D all these parameter are changing. So you have to make the change in accordance with that what minimum change is occurring in previous calculations.

So, that you will come across when you solve a few examples on design of shell and tube heat exchanger. Now, once you have this you have to use appropriate correlation depending upon whether flow is laminar transition or turbulent and calculate tube side heat transfer coefficient. So, all these expressions we have already discussed just keep in mind that in case of water you should use the specific correlation which is developed for water only. So, these are some steps to calculate tube side heat transfer coefficient.

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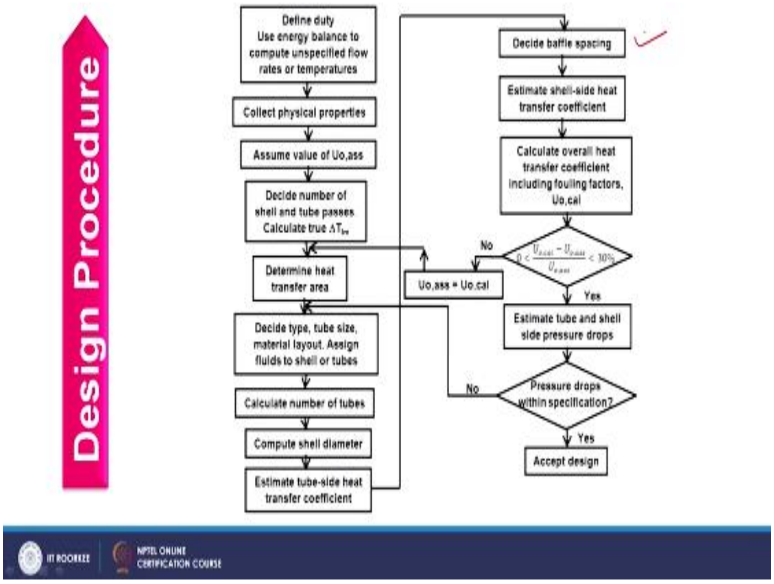

Now, next we will move to shell side. So for shell side calculation first of all we have to decide the baffle spacing and you understand that optimum baffle spacing should lie from 0.3 to 0.5 into shell dia. So, as an initial guess you can consider 0.3 into D s as baffle spacing.

Once you have that baffle spacing you can find out shell side heat transfer coefficient and for that you also have to fix the cut which cut the baffle cut.

So optimum range of baffle cut is 20% to 25%. So 25% is usually a good start so you can consider that as baffle cut. So 0.3 into D s baffle spacing 25% as baffle cut. Now, let us see how to estimate shell side heat transfer coefficient.

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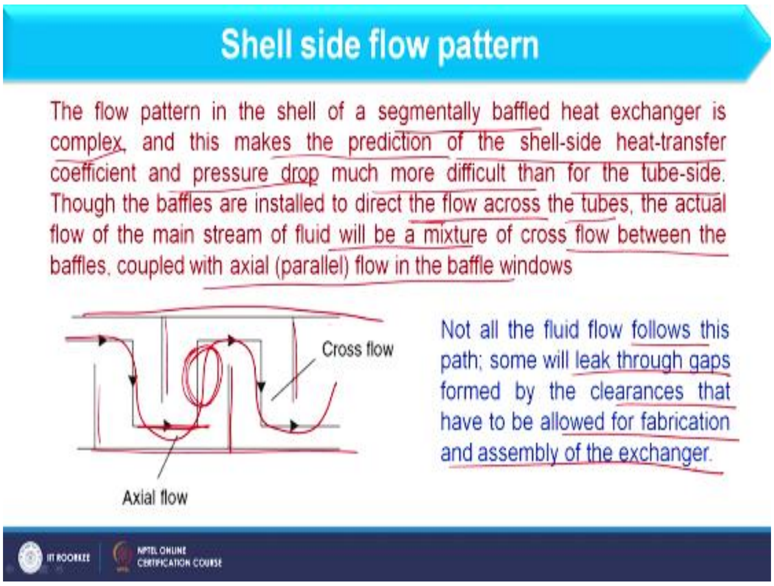

Now before going into detail of that we will see what should be the shell side flow pattern. So, flow pattern in shell side of segmentally baffled heat exchanger is complex and this makes the prediction of shell side heat transfer coefficient and pressure drop much more difficult than that for the tube side. Though the baffles are installed to direct the flow across the tube.

The actual flow of the main stream of the fluid will be mixture of cross flow between baffle coupled with axial flow in baffle window. What is the meaning of this? If you see this is schematic here we have the shell and these are basically the baffles. So, the movement of liquid will be like this. So, here we have the cross flow because fluid is flowing perpendicular to the fluid is flowing in tube side and here we have the axial flow that maybe counter current or concurrent with the fluid which is moving in tube side.

So, flow pattern is very complicated in shell side which is not the case in tube side. So not all the fluid flow follows this path some will leak through gaps formed by the clearance that have to be followed for fabrication and assembly of the exchanger because if I am considering that baffles are inserted in the tubes so holes should be prepared in baffles than only it will be inserted in the tubes.

So, the holes in the baffles depends on outer diameter of the tube and that hole diameter should be slightly more than the diameter of the tube than only it will be inserted. So that gap basically works as leakage. In the similar line, we have discussed the leakage between shell diameter and baffle diameter in previous lectures.

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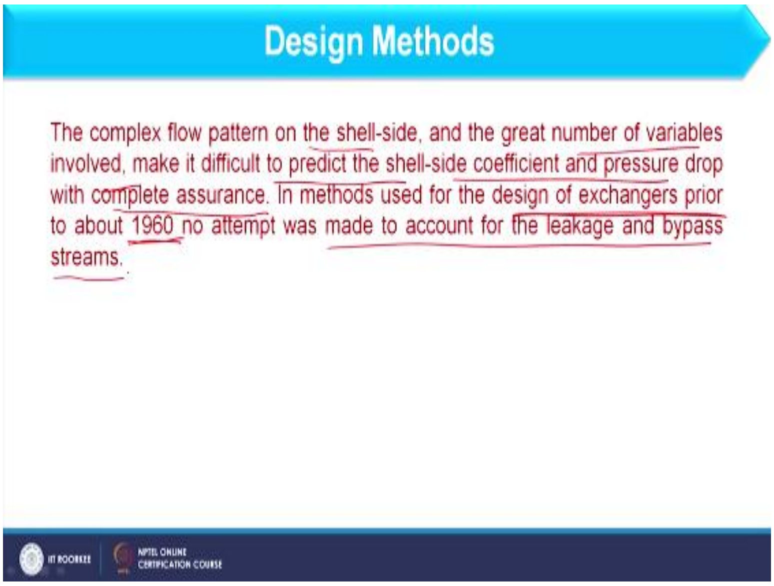

So in this way this is not the only pattern we have other patterns also, but for design purpose now we are considering this. So, the complex flow pattern on shell side and the great number of variables involved make it difficult to predict shell side heat transfer coefficient and pressure drop with complete assurance. In methods used for design of exchangers prior to about 1960, no attempt was made to account for leakage and bypass streams.

So, you can see the leakage and bypass streams are considered from 1960 onwards, but not before that and different methods are available we will discuss at time comes.

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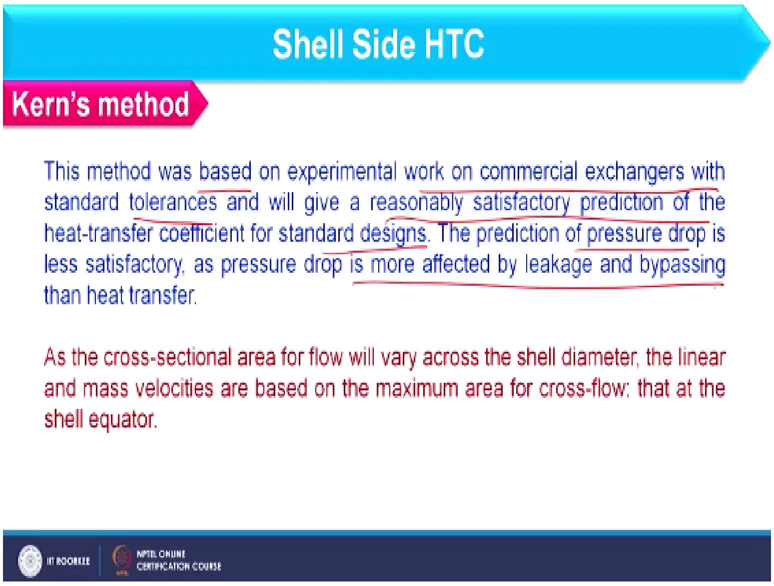

So now we will discuss the shell side heat transfer coefficient calculation and this is discussed based on Kern's method because here the design of shell and tube heat exchanger we are discussing based on Kern's method only, but all these methods different methods which are available these are specifically giving heat transfer coefficient and pressure drop calculation for shell side because that side the shell side is complicated side or complicated flow is there.

But in tube side no method is available whatever I have discussed till now that method is applicable for all methods. So, here we are considering Kern's method to calculate shell side heat transfer coefficient and this method was based on experimental work on commercial exchanger with standard tolerance and will give reasonably satisfactory prediction of heat transfer coefficient for standard design.

The prediction of pressure drop is less satisfactory as pressure drop is more affected by leakage and bypassing than heat transfer and Kern's method does not consider leakages and bypasses and that is very first method to design the shell and tube heat exchanger. So here we will discuss the steps which are to be considered to design.

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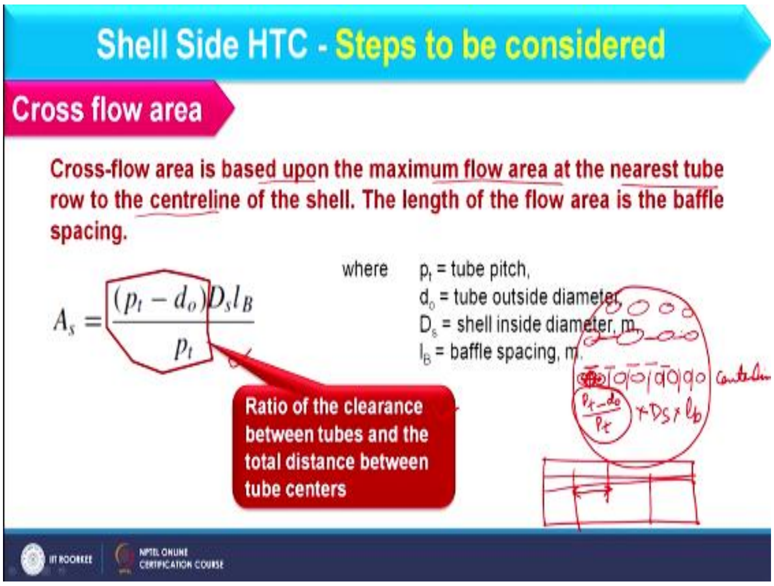

So, here we will discuss the steps which are to be considered to calculate shell side heat transfer coefficient using Kern's method. So first step is to find out cross flow area. Now what is that cross flow area? The cross flow area is based upon the maximum flow area at the nearest tube row to the central line of the shell. Now, if I consider the cross sectional view of shell here if I consider the central line we can have tubes like this.

So cross flow area which is considered in Kern's method that is based on the maximum flow area and maximum flow area where I can obtain that should be of course at the central line of the shell. So how can calculate the area in this? So, if you consider this we have to find out this area this gap because shell side only this gap is available otherwise there will not be any flow area because rest of the area is occupied by the tubes.

So here we have to consider the cross flow area as p t – d 0 D s l B / p t. So p t – d 0 / p t what is that? If I consider p t so that is basically this is p t and p t – d 0 it means I am focusing on this section divided by p t. So this p t – d 0 / p t dash is the fraction or is the ratio of gap this is basically the ratio of clearance between two tubes divided by the pitch. So, that is basically the ratio of clearance between tubes and total distances between tube centers so that is nothing, but the pitch only.

So in this way if I consider this gap and if I multiply that with D s, what is basically I am considering this, this, this, this it means complete flow area between the tubes at the central line. Complete flow length between the tubes at the central line it is still not the area. So how

I can consider the area? When I am considering the area, I should focus on the side view of this and here if I am having the tubes and in this way I put the baffle.

So maximum flow line or maximum flow distance is at the central line and flow area would be between these two baffles. So this into l B will give the flow area at the central line. So, if I am considering this A s that would be what? That is the gap between tubes into the baffle spacing. So it gives basically the rectangle type of section at the central line of the shell. So this A s is basically the maximum flow area because if I am moving over there if I am moving at upper side of the shell or below side of the shell.

This distance or the open area or the open distance will keep on decreasing. So, maximum will be find only at the central line and Kern’s method only considers this area not any other area. So that is again the work area where Kern’s method is applicable or we can say the limitation as well.

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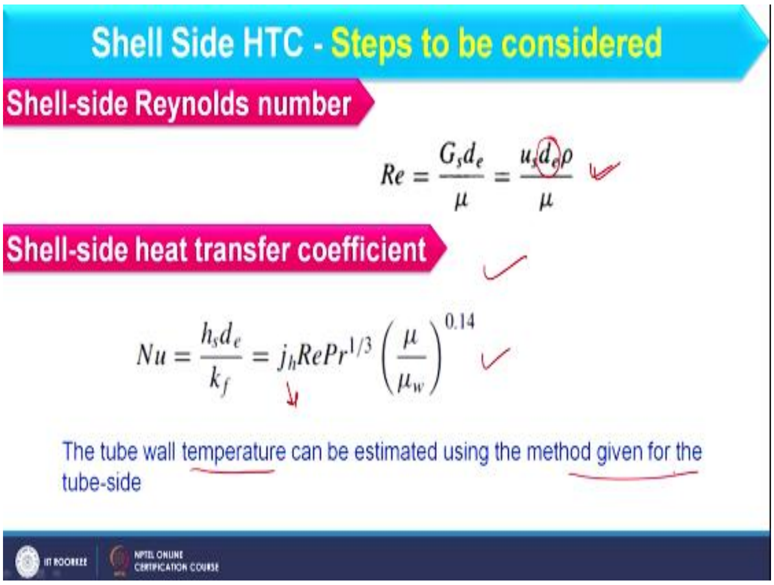

Now, once we have decided the cross flow area I already know the mass flow rate we can calculate the shell side velocity and after that we can calculate shell side equal in diameter. It will depend on the type of arrangement for square pitch we can use this expression and for triangular pitch we can consider this expression and after that I can find out shell side Reynolds number.

And that you can find using this equation where I am considering d e that is the equivalent diameter which we have just calculated and then we can find out shell side heat transfer coefficient using this expression where j h will depend on the baffle cut and further we can consider tube wall temperature to find out viscosity correction factor and method I have already explained in tube side.

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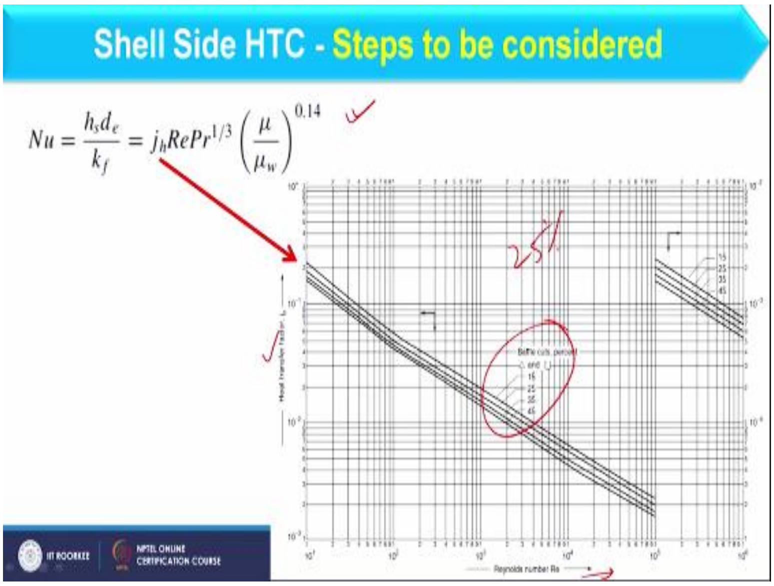

So, this is the expression for shell side heat transfer coefficient and j f you can find out from this graph where this is basically heat transfer factor j f it will depend on the Reynolds number and the baffle cut. So, baffle cut usually we consider as 25% that will be initial guess as baffle spacing we have considered 0.3 into D s as initial guess. So, in this way you can find out shell side and tube side heat transfer coefficients and we will continue the design of shell and tube heat exchanger in subsequent lecture also. So that is all for now. Thank you.