Heat Exchangers: Fundamentals and Design Analysis
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Lecture – 11
Tubular Heat Exchanger Types: Heat Transfer Co-efficient

Welcome. We are now trying to evaluate the heat transfer coefficient and pressure drop in tubular heat exchanger. Let us quickly look into the configuration or what we have learned in the previous classes.

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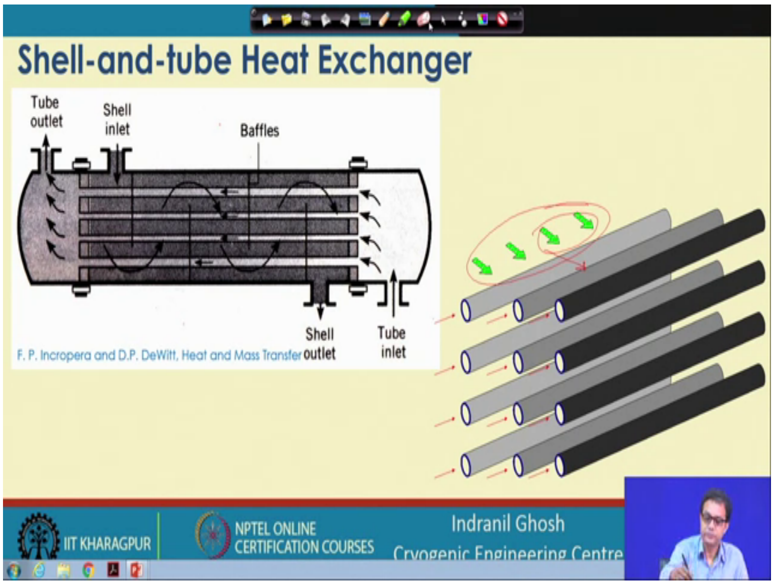

So, we were basically trying to find out the heat transfer coefficient on the sell side, because already we have talked about the tube side heat transfer coefficient that is for the internal flow. And now we are trying to look for the external heat transfer coefficient or the fluid flow, when the fluid flow is taking over the tube and we now want to find out the heat transfer coefficient for that configuration.

So, this is particularly valid or relevant for the fluid flow over the tubes in the sell side.

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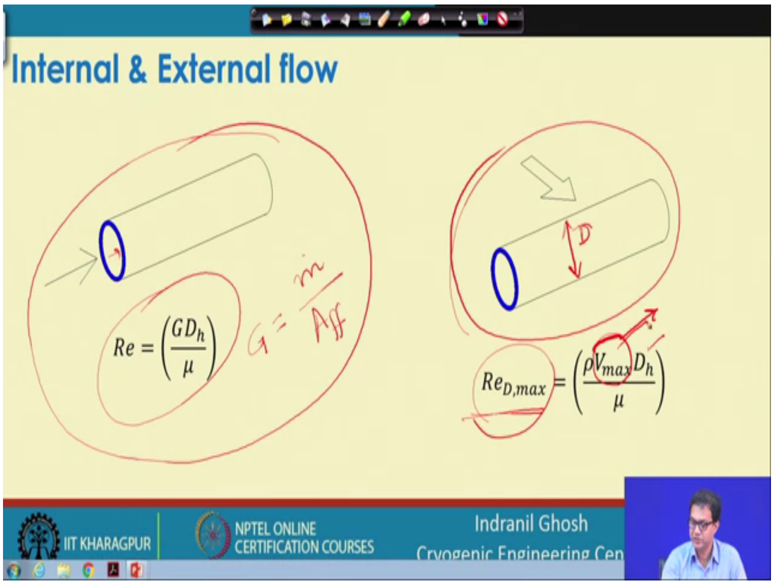

So, there we have trying to find out the, if you remember, in case of internal flow we have defined the Reynolds number by GD h by mu, where D h is the hydraulic diameter. And G was the mass velocity given by the mass flow rate per unit free flow area. And that is how the Reynolds number was defined for the flow, when the flow is taking place, through the tube inside the tube or we call it internal flow.

Whereas, if you remember that while talking about the external flow or flow over bank of tubes, we were looking for the maximum velocity, where it is occurring at the minimum frontal area or free flow area. And now we can understand that this has been done because we wanted to calculate the Reynolds number based on that maximum velocity, and we are defining the Reynolds number by rho V x D h by mu, where D h is the external diameter of that tube. And rho is the density mu is the viscosity of that liquid.

So, this is how we have defined the Reynolds number. So, that justifies our estimation of looking for the maximum velocity in case of that bundle of flow over bank of tubes.

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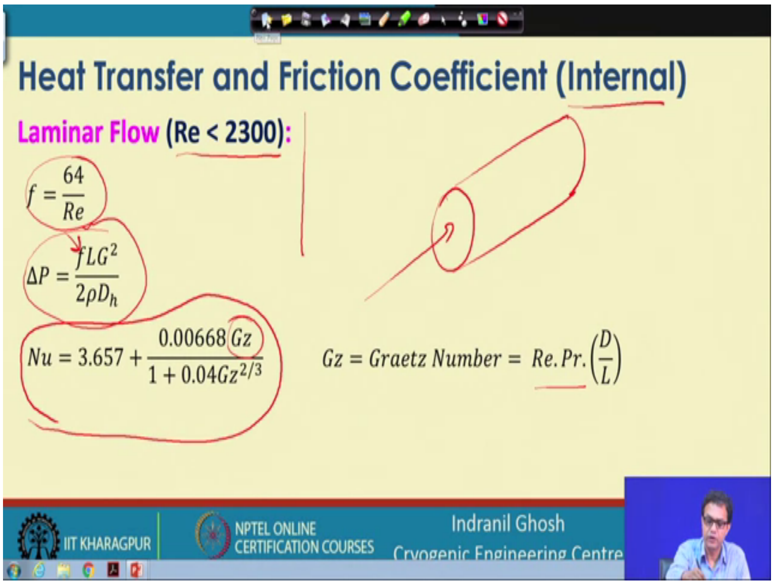

So now we will just quickly recapitulate, some of the things that we have learnt in the earlier class. For the internal flow we have if it is a laminar flow we have this kind of friction factor. And those friction factor will come in this relation for the pressure drop. And in case of one in case the laminar flow, laminar internal flow we have the Nessip number related to the Graetz number and Graetz number is given by this relation. This is where the flow is laminar and also it is internal flow; that means, the flow is taking place through the q inside the tube.

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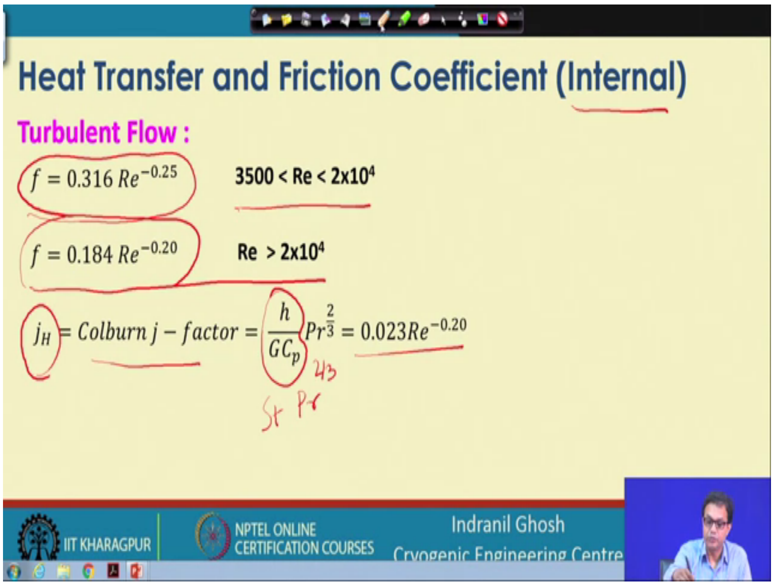

Now, if we go to the next I mean slide, this is also we have learnt, that in case of turbulent flow, we find that the friction factor is given by this relation, and this is valid for this Reynolds number. We have also learnt that for R e greater than 2 into 10 to the power 4 the friction factor varies like this. We have also told that the Colburn j factor, which is nothing but the Stanton number into Prandtl, Prandtl number to the power 2 third is equals to this relation, and this is valid for the turbulent flow, turbulent internal flow through a circular tube.

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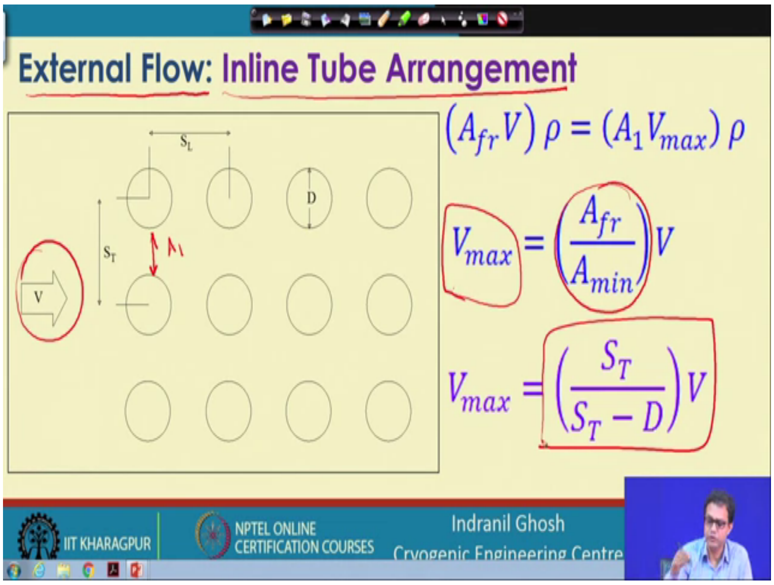

So now we will quickly go to the other 2 configurations that we have talked about. While talking about the external flow, now we are talking about external flow. And this is the in line arrangement of the tubes, where v is the velocity and we have estimated this V max to be the frontal area divided by the A min that is the cost 2, this is the minimum area A 1 and finally, it will be given by S T by S T minus D into velocity. So, this is for the inline arrangement of the tube.

Now, if we look into the other arrangement that is possible.

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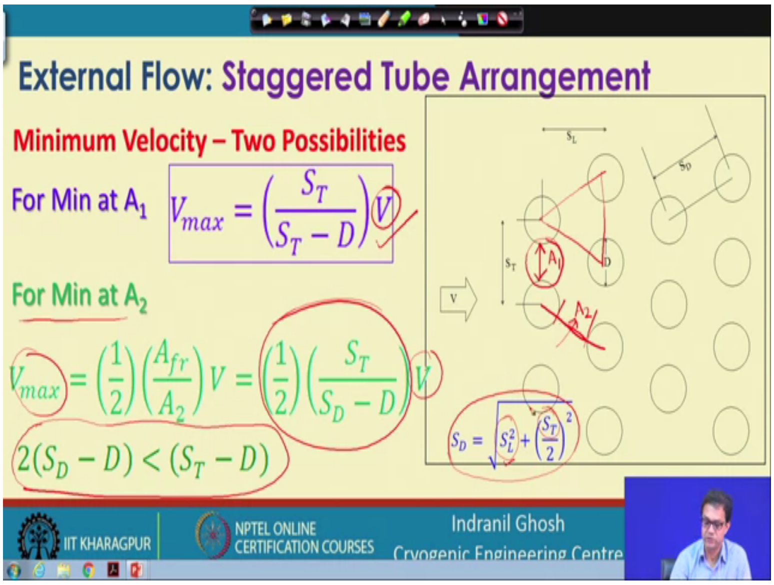

I mean that is in the staggered condition, we have seen that the tubes are in this staggered condition, and if we connect the center between this they will form a kind of triangle. So, this is what is the tri standard condition, where we have seen that this may the minima or the maximum velocity, it may occur at this location or it may also it may occur at this location this is called A 2.

So, we have also learnt if the minima is occurring or the area is minimum at this point or the maximum velocity is occurring at this point, we have the maximum velocity is related to the free stream velocity by this relation. And if the minimum is occurring at this point, or the maximum velocity is occurring at this point, A 2 we find that the V max is related to the free stream velocity by this relation.

And one of the criteria for occurring this V max at A 2 we have estimated it to be 2 S D minus D less than S T minus D, where S T can be related by ordinary Cartesian geometry. You will be able to relate the S T; S D this is the diagonal pitch. And it can be related to the longitudinal pitch and the transverse speech by this relation. So, this is up to this part we have learnt. And now how do we? Once we have calculated the maximum velocity we can calculate the Reynolds number.

And once we know the Reynolds number we would be able to find out the heat transfer coefficient.

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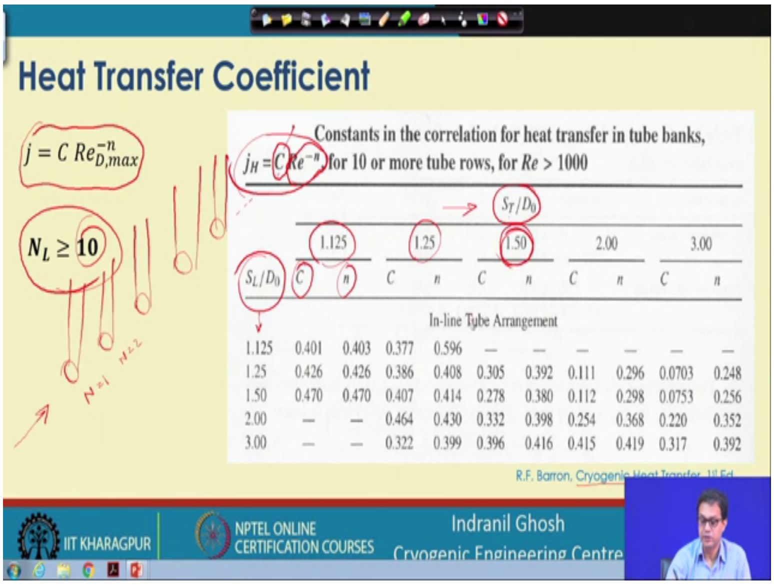

There in generally this has been taken from the balanced cryogenic heat transfer book, the Colvin j factor there it has been related to or it is related to this relation. Some constant and R e to the power minus n where this constant C and n will vary as a function of a S L by D 0 and S T by D 0. Where S T is the transverse speech, D 0 is the outside diameter of the tube. And S L is the longitudinal pitch and D 0 is the outside diameter.

So, these ratios are given on this side, and this is where you know S T by D 0 is varying on this side. So, we have C and n for each configuration. This is valid for number of rows more than 10; that means, when the flow is taking place like this, you know, we have n number of n equals to 1 n equals to 2. So, like this we have number of rows and along the direction of the flow. And it has to be more than 10 at least 10 or more than 10.

So, what happens if the number of tubes are less than 10? Then, obviously, there will be some kind of correction factor that you have to take in into account. So, we will come to that part later, but as you can understand that, this are some discrete numbers that I mean; it is not necessarily that the S L by D 0 will come as 1.125 or S T by D 0 will come as 1.25 or 1.5. So, we may finally, you know depending on the situation or the problem. We may find that we may have to interpolate some of the numbers.

So, we will now go to this is of course, given for the, if you look at this is given for the inline tube arrangement or this is where the tubes are just one after the other, ok.

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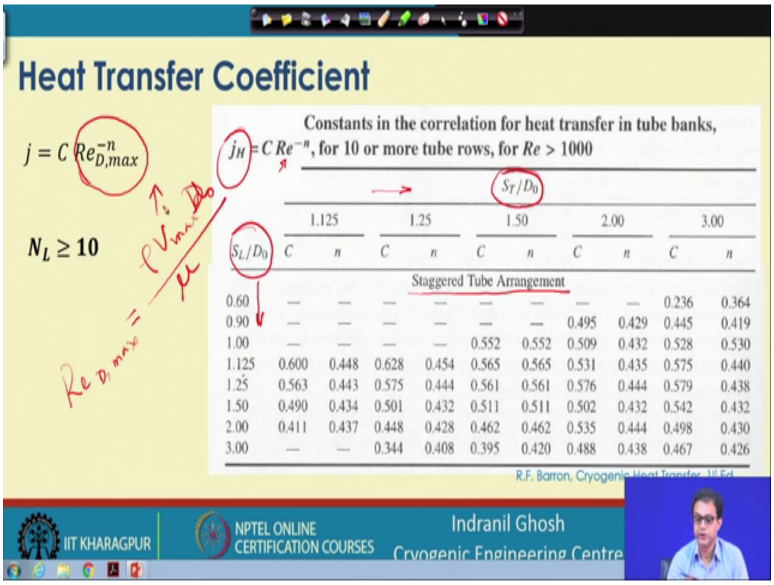

Now, what is about the staggered condition? We will find that for the staggered condition, now we have the heat transfer coefficients are correlations given for the staggered condition. Here also it is the same, I mean it has been given in the form of as a function of S T by D 0 and S L by D 0. So, here we have some numbers, and here we have similar numbers for S T by D 0. This is the Colvin j factor, related to the Reynolds number.

This Reynolds number is based on R e D max. Where this R e D max we have already learnt, that R e D max is related to the maximum velocity. And we have learnt how to this is rho V max into D or the external diameter or D 0 divided by mu. And we have already learned how to calculate the V max. So, this is the correlation given for the 2 banks where there the tubes are arranged in the staggered condition.

So now we will look into as we are talking that this is something like some discrete position that S L by D 0; say for example, is this number is 0.6 and 0.9. Now if by chance if something is coming at 0.85 or say it is not defined here. Say let us look into this position say between 1.25 and 1.5; if someone is finding that his number is 1.4 he may find it difficult to find out exactly what would be the number for the C and n.

So, as an alternative we have another I mean set of correlations given in this heat exchanger selection rating and thermal design part by (Refer Time: 13:05).

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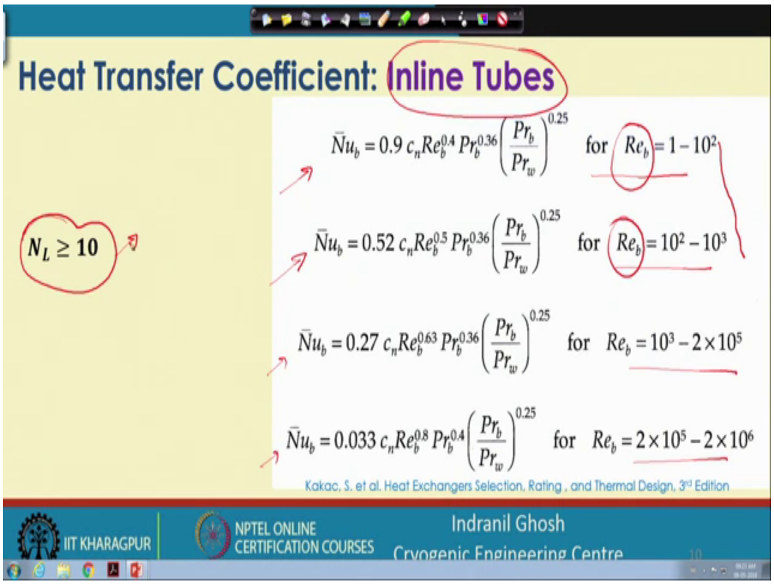

We find that here this is defined in as a function of; say, as a rather in as function of Reynolds number range different range of Reynolds number. And there are different correlations for the inline t of arrangements. So, depending on the Reynolds number or R e max, we will be able to find out what at the heat transfer appropriate Nusselt number this is related to I mean this correlation is again given by in terms of the Nusselt number. The earlier correlation was in terms of the Stanton, I am sorry, the Colvin j factor.

Now, here also we will find that this correlation is valid on different the number of rows and more than or at least number of rows are 10 or more. So, we have to apply that connection when the number of tubes or layers are rows are less than 10. So, we will come to that part later. So now, let us look into the configuration where the tubes are arranged in staggered condition.

So, similarly we have the heat transfer coefficients or correlations given for the, I am sorry, it is; so, these are the correlations for the staggered arrangement when the tubes are arranged in staggered condition.

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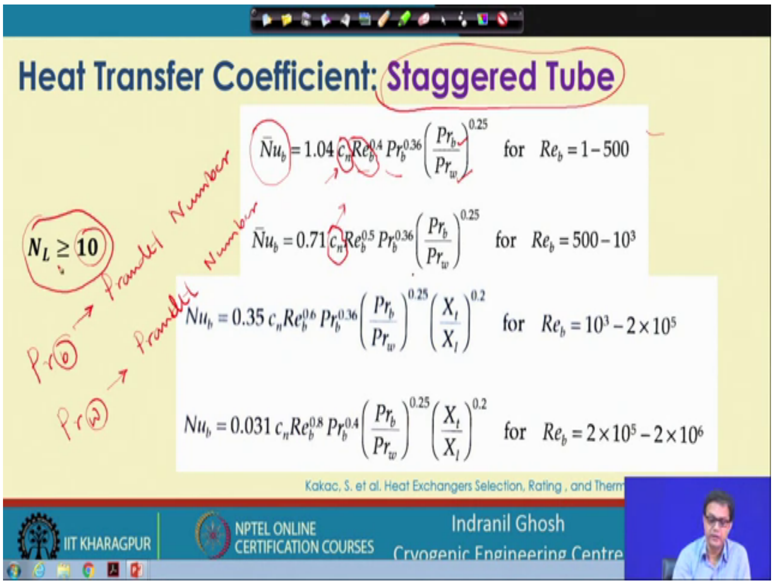

These are the set of correlations this is relating the Nusselt number, the Reynolds number, and Prandtl number, and this is Prandtl number b and Prandtl number w. So, they are the different, this is Prandtl number b and Prandtl number w. They are different both are the Prandtl number, but this is evaluated at a bulk mean temperature. This is evaluated at the wall temperature. So, that is the difference we have in these 2 numbers and this R e b also again this is evaluated at the bulk mean temperature.

So, you will also find another term here that is C n. Here also we find a number C n. And in the earlier correlation also you will find that they we have there is a term C n. And that C n takes care of the number of layers, if it is less than 10 it will be some factor. But if it is more or more than 10 or equal to 10 then it becomes 1. So, that sound the correction factor for number of rows less than 10 is taken into account automatically in this correlations.

So, now if we now we have the correlations available for the tube side. I mean sorry, the cell side where the tubes are arranged in either in inline configuration, or they are arranged in staggered condition. So, based on this information as we have said earlier, that we have to now take account of this C n how to estimate this C n, we will now find that there is a graph where we can correlate this C n, this is C n as a function of number of tubes.

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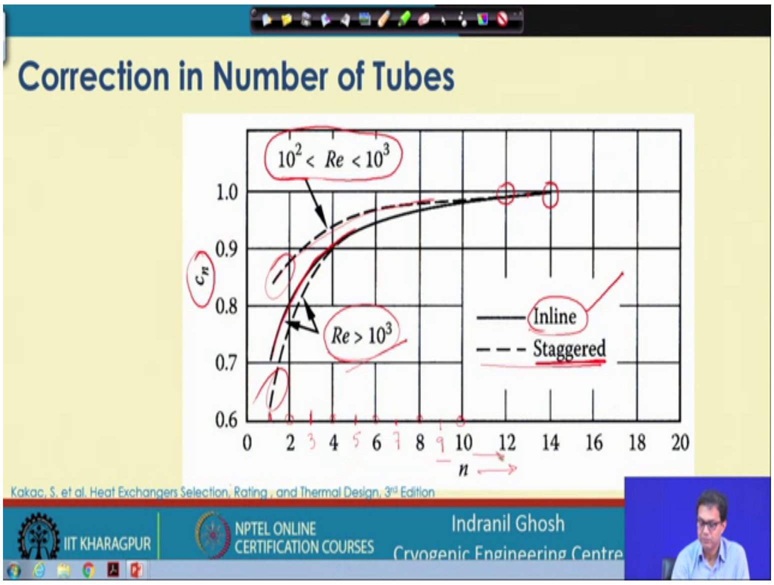

So, we see that if the number of tubes are 1, then we have certain kind of C n value for different R e values also. If the R e value is between 10 to the power 3 and 10 to the power 2 we have certain kind of correlation. If R e is greater than 10 to the power 3 or 1000, then we have some other kind of relation. Please note that this dotted line is for the staggered condition. And the continuous line is for the inline condition.

So, if we have the tubes arranged in inline condition, then we should look for this curve. If they are in the staggered condition, depending on the Reynolds number with either we look for this curve or we look for this curve. If the Reynolds number is more than 10 to the power 3, we find that this relation what I mean is this graph will tell you what would be the correction factor corresponding to number of rows equals to 2, 4, 6, 8, 10. And if it is more than 10 you can see it is almost reaching to one value. So, if it is a 14 number of rows, it is almost 1. If it is say about 13 it is 0.99. It is about this point and so on.

So, or it is not only giving it is for 2, 4, 6, 8. The intermediate value can also be taken as 3, 5 also, we can evaluate it at this numbers 9, etcetera. So, depending on the number of tubes if it is less than 10 or 12, then we can accordingly take care of that correction factor that we have to incorporate within that correlation that has been given in the earlier slides.

So now we will try to quickly look into a small problem that we can try to solve.

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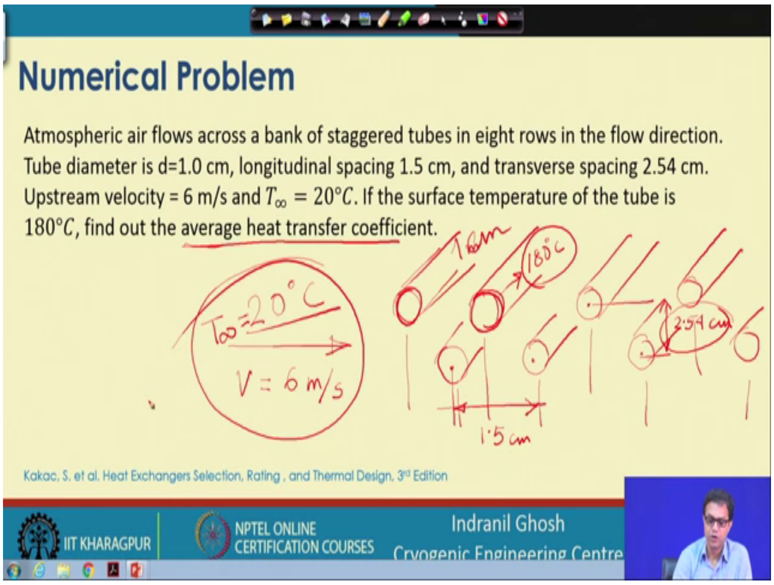

Here it is saying that atmospheric air is flowing across a bank of staggered tubes and the number of tubes are 8. So, they are in the, they are arranged in the 8 rows in the along the flow direction. The diameter of the tube is given the longitudinal spacing, and the transverse spacing is also given. The upstream velocity is specified, and it is flowing at a condition of 20 degree centigrade. So, if the surface temperature of the tube is maintained at 180-degree C, then we are suppose to find out the average heat transfer coefficient.

So, let us try to solve this problem. So, what are the things, that has been given to us we already know that we have some number of tubes. How many number of layers are there? Like this we have 1, 2, 3, 4, 5, 6, and we have to add 2 more. So, like this we have 8 number of rolls. So, 1, 2, 3, 4,, 5, 6, 7 and 8, and the flow direction is this. This velocity V is 6 meter per second. The diameter of the tube is already specified it is diameter is 1 mm sorry 1 centimeter. And the longitudinal spacing; that means, the centre to centre this distance is how much? 1.5 centimeter; we have the transverse spacing; that is, this to this is 2.54. It is not to the scale, and it is looking the smaller dimension is looking more than this 1, but ee if it is properly drawn. You will find that this is widely spaced, ok.

And what is given is that this fluid is flowing at a temperature T infinity is the cost to 20 degrees centigrade. And the surface of these tubes are maintained at a temperature of 180 degree centigrade. So, what we know now try to find out is an average heat transfer coefficient for this configuration.

So, basically if you look into this configuration, you may find that in a shell and tube heat exchanger, we may have this kind of arrangement of the tubes and over which the fluid flow is taking place. And we are interested to find out the heat transfer coefficient for this configuration. So, for such configuration, often we specify or we supply you the heat transfer coefficient, but in reality we may have to calculate it. And we now try how to calculate this kind of heat transfer coefficient.

So now what is the starting point?

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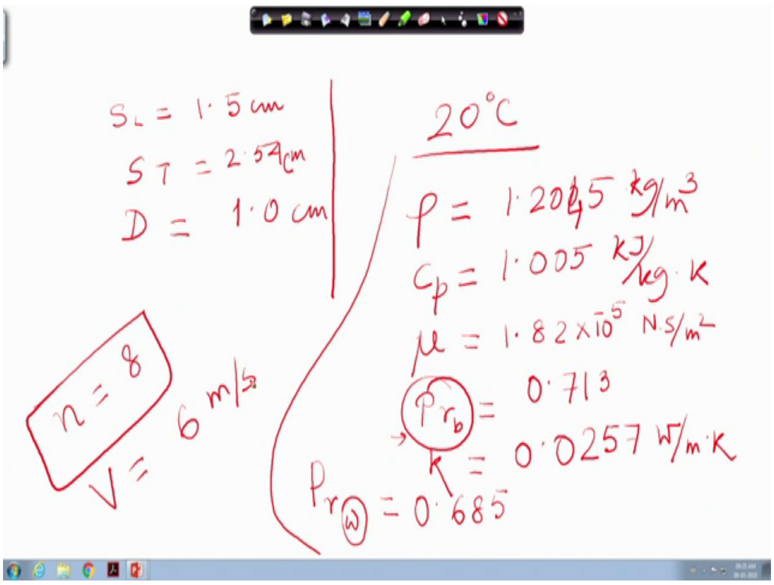

We have already been given that a S L longitudinal pitch is 1.5 centimeter. S T is 2.54 centimeter, and diameter is equals to 1 centimeter. And first of all we have to find out the fluid properties. We evaluate the fluid properties at 20 degree centigrade. And the density is 1.2 double 0, sorry, 2 0 4 5 kg per meter cube. Then we have the C p this is equals to 1.005 kilo joule per kg Kelvin. Then we have the viscosity 1.82 into 10 to the power minus 5 Newton second per meter square. Then we have the Prandtl number equals to 0.713. And the thermal conductivity is equal to 0.0257 watt per meter Kelvin.

And also this is Prandtl number b and evaluated at the bulk mean temperature. And P r w; that is, the wall temperature that is 180 degree centigrade, this comes out to be 0.685.

So, these are the values we know, the number of rows are 8, and the velocity V is equals to 6 meter per second. So, with this information now we try to calculate the different parameters.

What are the different parameters that we have to find out?

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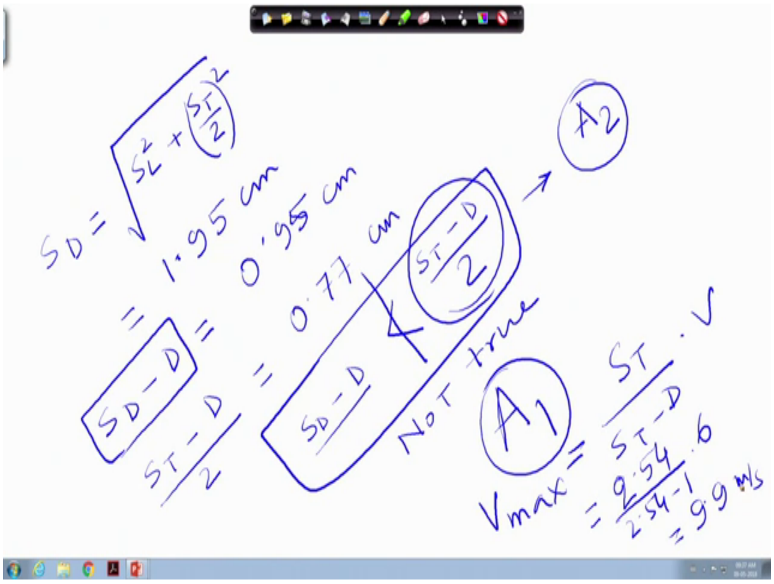

First of all, we calculate the diagonal pitch, that is equals to root over S L square plus S T by 2 whole square and then square root. So, this comes out to be 1.95 centimeter. Then we have is D minus D, that is equals to 0.9 5 meter. You can understand why we are trying to find out S D minus D, because we do not know exactly at what location that minimum free flow area is there, or we are rather trying to find out where the maximum velocity is occurring.

So, then we try to find out S T minus D by 2, and that comes out to be 0.77. So now, we see that S D minus D less than S T minus D by 2 that is the correla I mean condition that is necessary for the velocity to be maximum at A 2. But this is not getting satisfied, because 0.95 this is equals to 0.95, and this is 0.77. So, this condition is not true. So, this is not I mean less than. So, we can understand that the minimum area is occurring at A 1, and we have to evaluate the velocity V max is equals to S T by S T minus D and V. So, this will come out to be S T was how much? S T is 2.54, and 2.54 minus 1 into 6 this will come out to be 9.9 meter per second.

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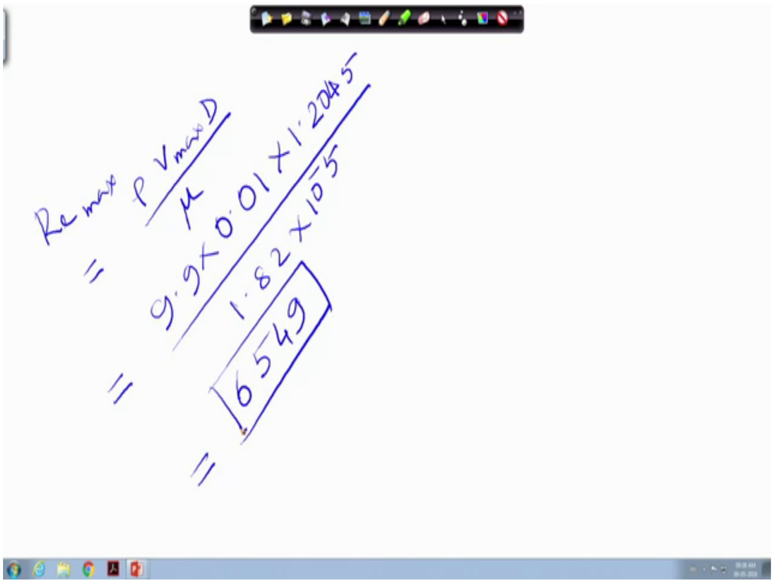

So, once we know the velocity maximum, maximum velocity then we can calculate the R e max. And that will be V max rho into rho into V max into D divided by mu, and this becomes 9.9 multiplied by 0.01 meter is the diameter. And 1.2045 is the density of the air, divided by the viscosity 1.82 into 10 to the power minus 5.

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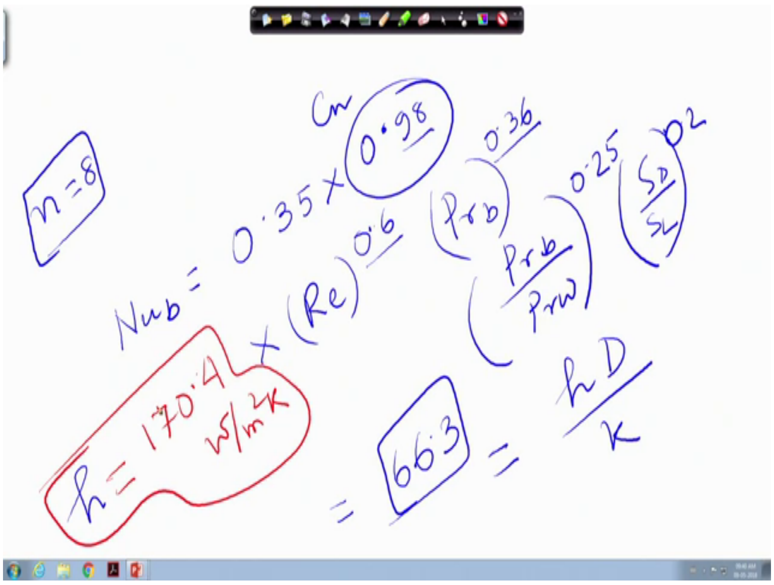

So, this gives you the Reynolds number 6549. So, once we have decided the Reynolds number, we can look for the appropriate correlation if you go back you will find the appropriate correlation for this condition. And you will find that the Nusselt number the equals to 0.35 into 0.98, 0.98 is coming for C n, because we have n equals to 8, and corresponding to n equals to 8, we have to look into that chart and there we will have the correction factor 0.98, then we have R e to the power 0.6. This is corresponding to an R e equals to 6549.

So, there we will find that the R e variation is R e to the power 0.6. Then we have P r evaluated at the bulk mean temperature. That will come at point P r b, P r b to the power 0.36. And then P r b by P r w, that comes out to be 0.25, and then you have is D by s longitudinal as 0.2.

So, this when you evaluate, it comes out to be 66.3. So, once we know the Nusselt number this can be related to h D by k. And we have the value of k we have the value of b, we can find out the heat transfer coefficient that will come out as 170.4 watt per meter square Kelvin.

So, in general, that value which we otherwise supplying in different heat transfer calculations. Now you have learned how to calculate it from different correlations.

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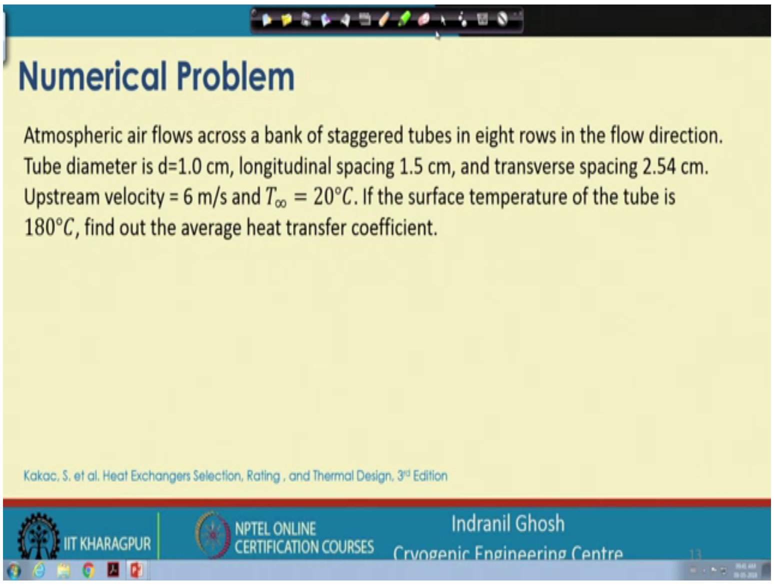

And with that expression of the heat transfer coefficient, we would now be able to find out I mean different other parameters which are necessary.

Thank you for your attention.