Heat Exchangers: Fundamentals and Design Analysis
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Lecture - 07
Design and Simulation of Heat Exchangers - Numerical Problem

In continuation to our earlier discussion on the Design and Simulation of Heat Exchangers, today we will try to do some Numerical Problem.

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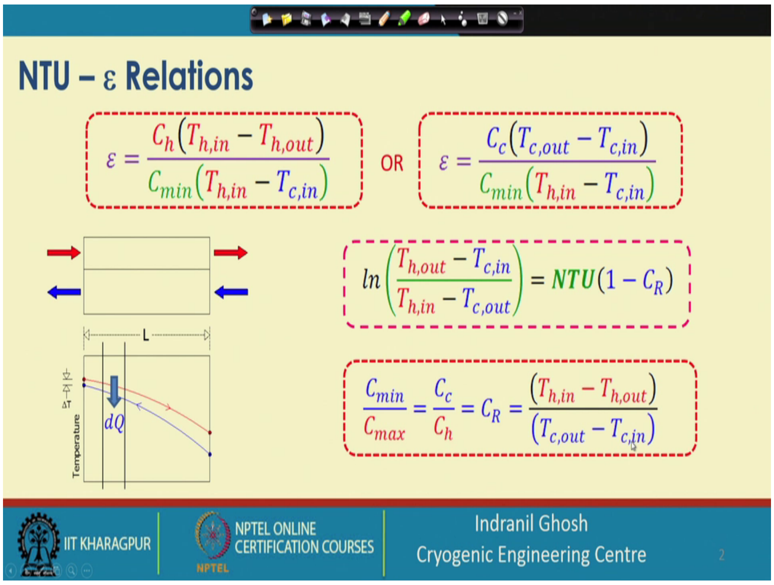

And in that problem before going into that problem let us see what we have learned so far in summary of the problems that we have learned in the last class; we have talked about the NTU epsilon relation where in case of a counter current exchanger, we have seen that this is the expression for the heat exchanger effectiveness either it can be expressed in terms of the hot fluid heat capacity or it can also be expressed in terms of the cold fluid heat capacity. And depending on the hot fluid and the cold fluid being the minimum capacity fluid; we will either have this expression or this expression and this may be cancelling out or may not cancel.

Now in continuation to that we have also seen that if we make an energy balance between these 2 fluid streams, we can get a relation something like this which will involve the epsilon and NTU. And with the help of this expression of the C R or the heat capacity rate ratio which is defined as C min by C max. We can also find that we will have expressions like this one which has been you know we in the last class we tried to arrive at this expression.

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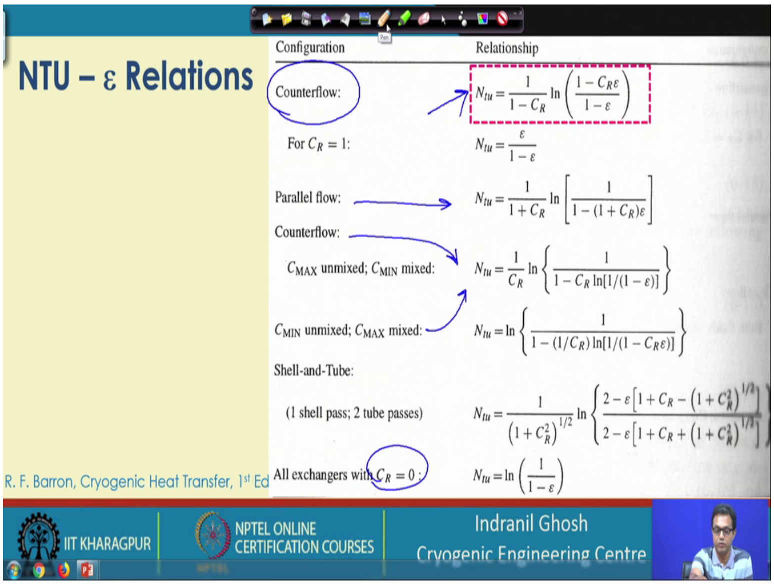

So, this is you have to mind that this expression is for the counter flow heat exchanger an element we have tried. And in case of parallel flow obviously the expression will change and even in case of counter flow where fluid is getting mixed or unmixed also. We will try to solve this problem later on when we discuss about the mixed and unmixed fluid problem.

We will find that there are series of expressions for the epsilon and the NTU and; obviously, the heat capacity rate ratio. And for all exchanges when C R equals to 0; what is mean by C R equals to 0; the C min by C max equals to 0 or this is particularly you will find that this corresponds to condensing or evaporating heat exchanger. So, in that case we will have a simple relation NTU equals to l n 1 by 1 minus epsilon.

Now, depending on our situation we may also have you know; it will be such that we may be knowing the epsilon and in that case we can find out the NTU from this relation. But in case if it such happens that NTU is known, we are trying to find out the epsilon in that case we will have a slightly different relation given by.

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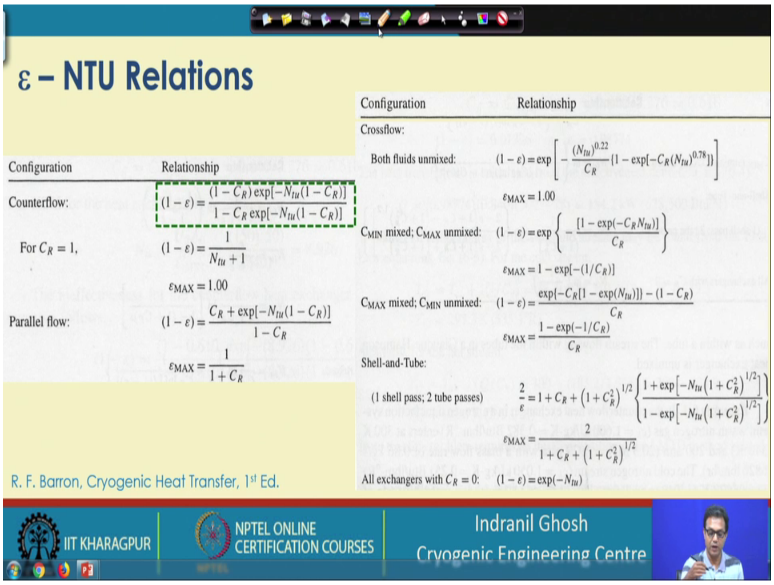

Say that in case of corresponding I mean the counter current exchanger; the corresponding expression would look like this. It is same as before except that the NTU and C R is on the right hand side as known and 1 minus epsilon is on the left hand side. So, if the NTU and C R is known; we can directly calculate the epsilon from this expression. So, again like counter current exchanger and parallel flow heat exchanger; we have for cross flow and shell NTU and all exchanges these are the corresponding equations.

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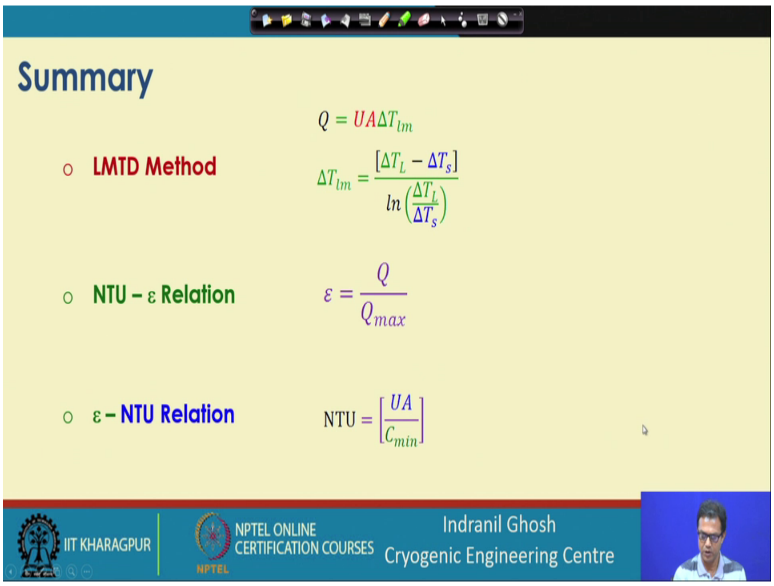

So, with this back ground if we now summarize what we have learned so far is basically we have talked about the LMTD method. We have also looked for the epsilon NTU and NTU epsilon relations.

Now, based on these relations; we now can try to solve some example. We have taken this example from interpreter and David heat and mass transfer book.

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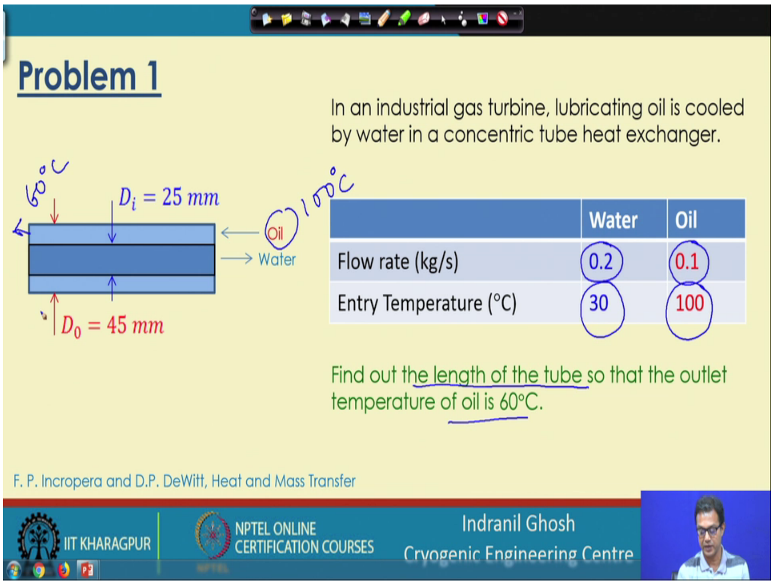

And it is basically dealing with the industrial gas turbine heat exchanger where the lubricating oil is getting cooled using the water in a concentrate tube heat exchanger. So, basically it is a tube and cube heat exchanger where the internal diameter of the tube is 25 mm whereas, the outer diameter is 45 mm. The thickness of the inner tube has been neglected and the oil is flowing through the annular space. Whereas, water is flowing through the internal tube; the flow rate of water and that of the oil is given then inlet temperature is known.

So, the entry temperature of water we can see that it is 30 degree centigrade whereas, that of the oil is 100 degree centigrade. The water flow rate is 0.2 kg per second; the oil flow rate is point 1 kg per second. Now what we are supposed to find out is the length of the tube so that the exit temperature of the oil is 60 degree centigrade. So, this oil is entering at 100 degree centigrade and we are trying to find out the length of this tube so that this oil will come out at 60 degree centigrade.

Now, we have to determine the length of the heat exchanger; so, basically we can understand that we have some of the information's known and we intend to find out the length of the exchanger or the dimension of the heat exchanger. So, basically it is a sizing problem; so now let us try to see how we can solve this problem. So, first of all if we have to find out the sizing problem, if we want to apply the LMTD method what we need to know is the exit temperature of all the 4 fluid streams.

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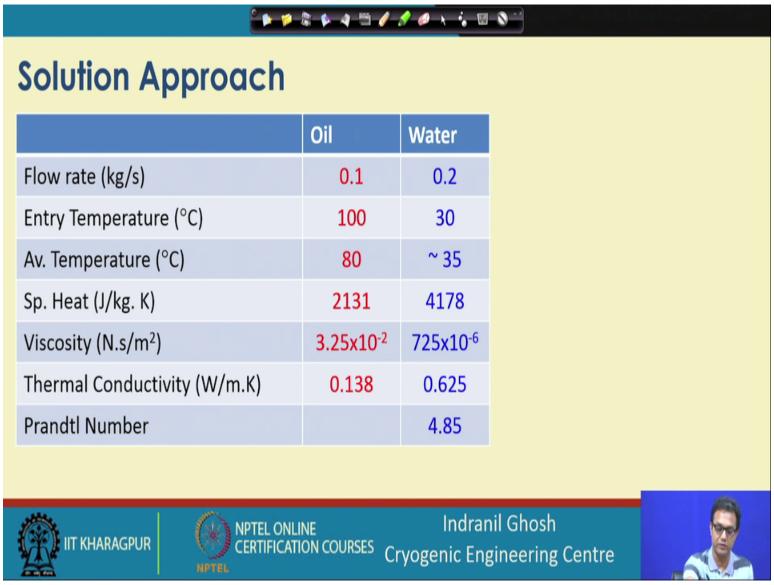

	Oil	Water
Flow rate (kg/s)	0.1	0.2
Entry Temperature (°C)	100	30
Av. Temperature (°C)	80	~ 35
Sp. Heat (J/kg. K)	2131	4178
Viscosity (N.s/m^2)	3.25×10^{-2}	725×10^{-6}
Thermal Conductivity (W/m.K)	0.138	0.625
Prandtl Number		4.85

So, if we go to the problem statement we will first find out that the flow rate what are the things that are known and what are the things that we have to find out or assume is like we have been given this oil flow rate, water flow rate, entry temperature of oil, entry temperature of the water.

And now we need to find out the exit temperature of water because already we have been told that we intend to find out I mean measure the; length of the exchanger so that the exit temperature of the oil will become 60 degree centigrade. So, we know what is expected from this heat exchanger.

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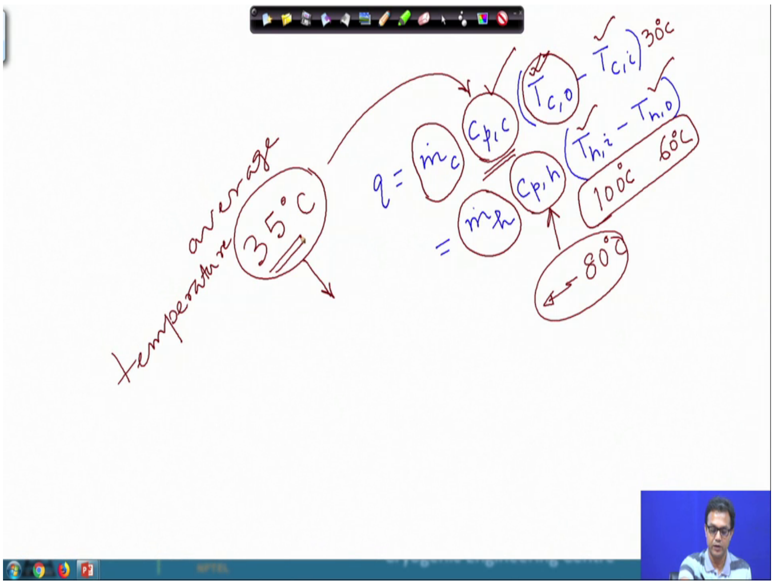

So, if this exchanger is trying to cool the oil to 60 degree centigrade; then what is the amount of heat transfer that is there? q is equals to m dot of c; C p c and then T c out minus T c in and that is equals to m dot h C p h and T h in minus T h out.

So, if we have to find out this heat transfer; let us see what are the parameters those are known to us? We know this mass flow rate of the cold fluid, what is the cold fluid? The water is the cold fluid, we know the mass flow rate of the hot fluid that is also known this T c o is known, the cold entry temperature that is the entering at 30 degree centigrade; we have no idea about T c; I am sorry this is T c in is known this T c out is to be find out.

And T hot in is known T hot out is expected to be 60 degree centigrade. So, we have this is 60 degree, T hot in is 100 degree centigrade T c i is 30 degree centigrade. So, what we do not know is T c o the hot cold exit temperature and this property values of the hot and cold fluid are supposed to be known to us.

Now, the hot fluid average temperature is already known to us; it is 80 degree centigrade. So, we can estimate the fluid properties at 80 degree centigrade. So, the average fluid properties of the hot fluid at an average temperature of 80 degree centigrade; we will be evaluating. But that advantage is not there with this cold fluid because this cold exit fluid temperature is not known, we do not have an idea about the average temperature of the cold fluid. So, we will make an assumption; say here in this case we are making an assumption that the exit temperature would be average temperature rather of the cold fluid is 35 degree centigrade. Otherwise we would not be able to find out the heat capacity of or the specific heat of the cold fluid to estimate the exit temperature.

So, if we are making an average temperature assumption for the cold fluid; then we will estimate the specific heat of the cold fluid, and then we will try to find out the exit temperature of the cold fluid, and then we will find out whether it is a good assumption or not. So, at 35 degree centigrade average temperature of the cold fluid let us go back we have this at the average; I mean fluid properties out of which you see we have the C p, this is the hot fluid capacity, this is the cold fluid capacity, this is the viscosity values. And the thermal conductivity and the Prandtl number of the water is given here; we have not taken this one because we will find that it is not relevant for I mean it is not needed in the problem statement.

So now with this values; if we now try to estimate the exit temperature of the cold feet.

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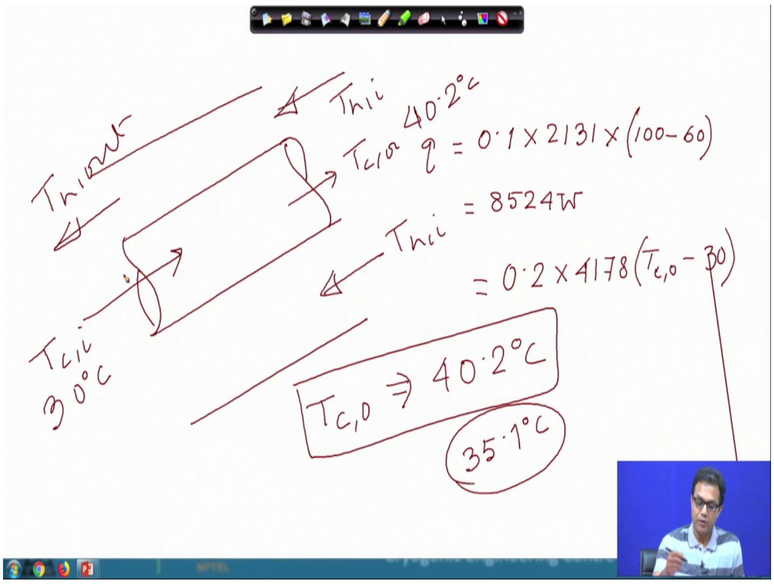

So, we will see that q equals to m dot of the hot fluid that is equals to 0.1 then we have 2131 multiplied by T hot in that is equals to 100 degree centigrade and it is coming out at 60 degree centigrade. So, this is the amount of heat getting transferred through the hot fluid; so, it is 8524 Watt. Now if this is the hot fluid getting transferred from this is the T h in, this is T h out and this is an annular space through which the oil was flowing out.

And this is the T h, this is also T h i and this is through which T c i and T c out cold exit temperature.

Now we can equate this one to what is the water flow rate 0.2 multiplied by; what is the cold fluid specific heat? The cold fluid specific heat was 4178 and multiplied by T c o minus T c in is 30 degree centigrade. So, this comes out to be this will make T c exit to be 40.2. So, now we have been able to estimate the cold exit temperature. So, this is entering at 30 degree centigrade going out at 40.2 degree centigrade; what is the average temperature? Then it will come out to be 35.1 degree centigrade and this is supposed to be a very good approximation that we have taken for the average temperature of the cold fluid.

So, now we have both the inlet and exit temperatures known for both hot and cold fluids. So that means, we have along with the flow rates; these are the flow rates, then we have the entry temperature. Now we know also the exit temperature and the fluid properties like viscosity thermal conductivity etcetera and the Prandtl number.

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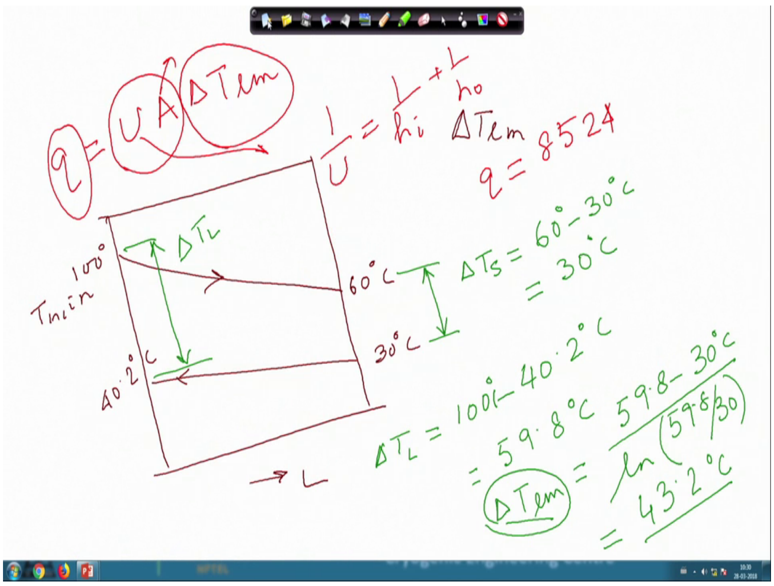

So, with this information; we can now try to calculate the delta T log min; delta T log min how do we know that? So, in case we this is a counter current exchanger, this is along the length we know the hot fluid temperature is 100 degree centigrade; T h in and the hot fluid is moving out at 60 degree centigrade. The cold inlet is 30 degree centigrade and it is moving out at 40.2 degree centigrade.

So, this is what is the temperature profile; now we will try to find out the delta T l m. So, here this is the delta T say the smaller one; we can understand this is the smaller one; so this is nothing, but 60 minus 30 degree centigrade. So, it is 30 degree centigrade what is about this one? This is the delta T large, this delta T large is 100 delta T large is equals 100 degree minus 40.2 degree centigrade and so this comes out to be 59.8 C.

So, the delta T l m is delta T large minus delta T small; so, 59.8 minus 30 degree centigrade divided by l n of 59.8 divided by 30; so this comes out to be 43.2. So, now, we have the idea about the l m T d; delta T log min temperature. Now, what else do we need? We also know already we have seen that q is known; q we have estimated 8524. So, in that expression q is equals to UA delta T l n. So, out of which we have already been able to calculate the delta T l m; we have been able to find out the q. What we need to know is the overall heat transfer coefficient and from there we will be able to find out the area.

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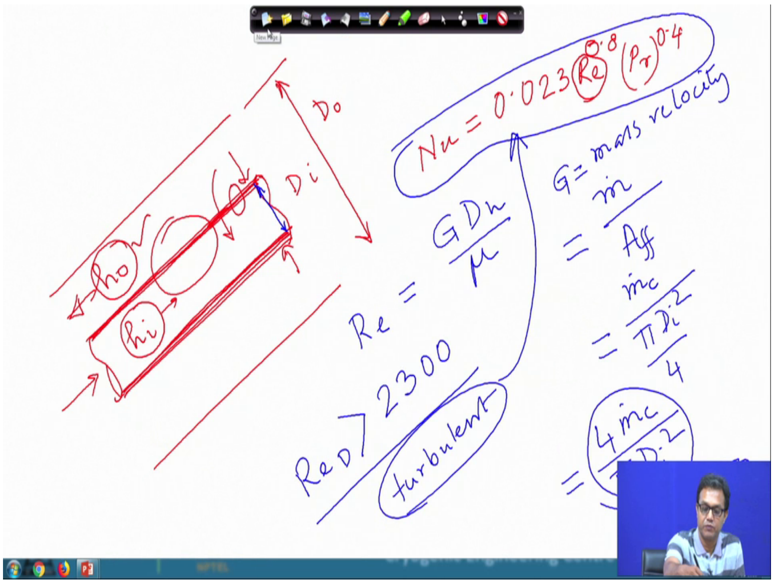

Now this U is basically 1 by U is equals to 1 by h i plus 1 by h o or if we look at our geometry; we will find that this is the internal tube and we have the external tube. The heat transfer is taking place through this wall and so this heat transfer surface area is of our main concern.

Here this is the D i that has been given and this is the D 0; what we are trying to find out is the heat transfer coefficient between this 2 regions: one is the internal heat transfer coefficient, another one is the heat transfer coefficient of this annular space. So, for internal heat transfer coefficient this is the flow through the pipe and we know how to estimate the heat transfer coefficient.

Now for this annular flow we need to find out how to estimate the heat transfer coefficient in the annular space. And what is the heat transfer area involved? This is this internal surface area is the area which is involved, where this heat is getting transferred from the hot fluid to the cold fluid. And please remember that we have neglected the thickness of this internal tube so, that the heat transfer resistance offered by this wall is negligible.

Now, in case of this internal flow; we know that this heat transfer coefficient Nu is given by the Nusselt number for the internal flow is given by 0.023 into R e to the power 0.8 into P r to the power 0.4. So, this R e is the Reynolds number and how to find out the Reynolds number corresponding to this water flow through this internal tube? This R e is G D h by mu; what is this G? G stands for the mass velocity; G is called the mass velocity. So, this is nothing, but the mass flow rate divided by the free flow area, but is the free flow area here, this is the free flow area or pi d square by 4. So, m dot is m dot c cold fluid mass flow rate divided by pi D i square by 4.

So, this is nothing, but 4 m dot of the cold fluid divided by pi D i square. So, this can be obtained as we already we know the mass flow rate of the cold fluid, the cold fluid mass flow rate is 0.2 and we can estimate it to be 1 0 1 4 0 5 0. So, the Reynolds number is more than the R e d is more than 2300; that means the flow is in the turbulent region. This is in the turbulent region; so we have this Nusselt number is equals to this part is we can use this detest voltage equation for finding out the heat transfer coefficient.

So, now for this Reynolds number if we put this value over here and the Prandtl number was given as the Prandtl number we already know, and we can now try to find it out the heat transfer coefficient from this relation.

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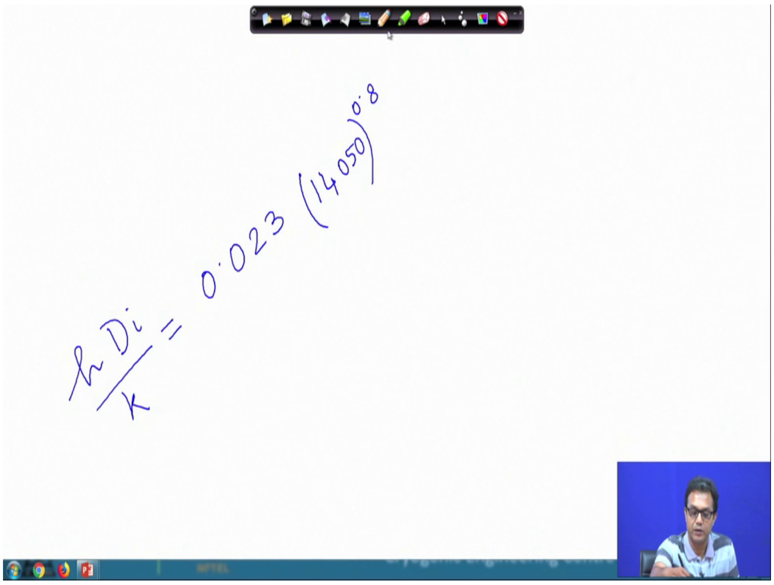

So, the Nusselt number is basically h D i by k is equals to 0.023 into R e; we have obtained as 14050 to the power 0.8. And the Prandtl number was how much was the Prandtl number? We have let us go back and see how much is the 4.85 is the Prandtl number.

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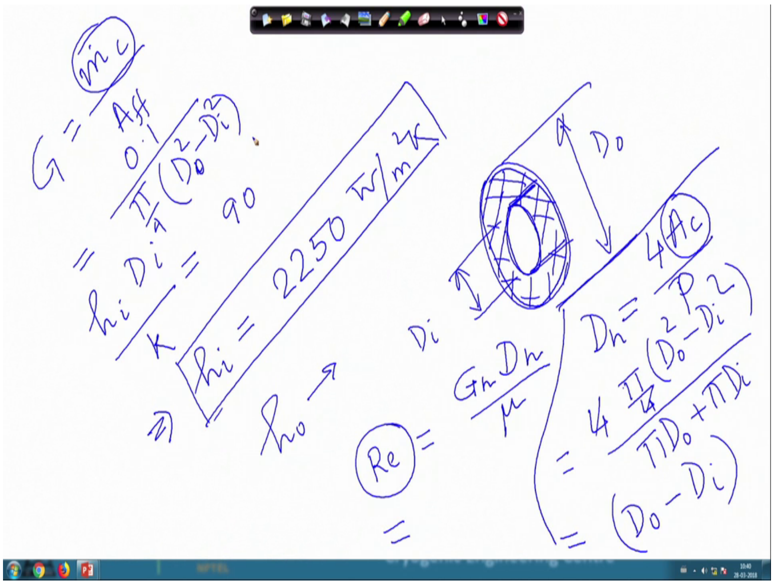

So, if we put all these values I mean values we can obtained; we can obtain the h; h i, D i by k is equals to the Nusselt number. And the Nusselt number is nothing, but 0.03 it will be estimated to be 90 and from there we can calculate the h i to be 2250 Watt per meter square Kelvin. So now we know the internal heat transfer coefficient.

So, with this knowledge now we have to go to the next parameter that is the heat transfer coefficient of the annulus passage. So, what is that annulus passage? The annual passage is just like this where we have the internal diameter is D i this is D i and this is D 0. So, for this case we need to find out what is the heat transfer coefficient.

So, before going into that one we need to find out what is the Reynolds number for this annular space. So, again if we try to find out this is the G of the hot fluid and D h of this annular space, what is the hydraulic diameter corresponding to that annular space? This is say if we, let us try to find out that value also. This annular space hydraulic diameter; if we say from the basic dimension and basic definition of the heat transfer I mean hydraulic diameter we know this is 4 Ac by the weighted perimeter.

What is Ac? This is the cross sectional area through which the flow is taking place. So, this is just nothing, but 4 into pi D o square minus D i square divided by; the weighted perimeter is this is the weighted perimeter as well as this is also the weighted perimeter. So, we have pi d 0 plus pi d i; so, in that case this comes out to be, there would be of course, another 4 pi d square by 4; D 0 square minus D i square. So, this 4 will be cancelling out, this pi is getting cancelled. So, we have finally, D 0 minus D i as the hydraulic diameter corresponding to this annular space.

So, in that case the Reynolds number corresponding to this is G is how much? G is basically the cold fluid mass flow rate divided by the free flow area; what is that free flow area? The free flow area you will be able to find out that as pi by 4 pi D 0 square minus D I square. And this cold fluid mass flow rate is 0.1 k g per meter square.

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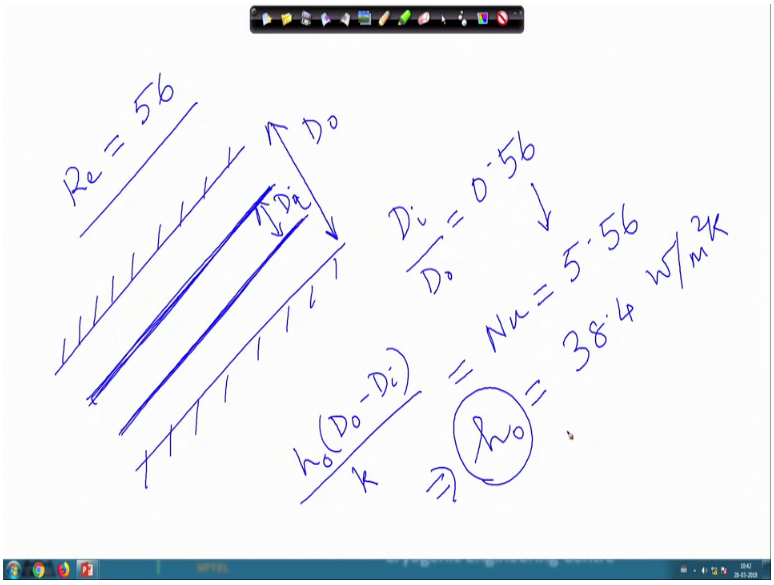

So, with this values if we try to; if we try to estimate the Reynolds number corresponding to that value, it becomes 56 for that annular space.

Now, for this annular space we have expression when we have an insulated outer boundary and the internal wall temperature remaining constant. So, for this type of configuration the heat transfer coefficient this is D i; so, D 0 by D i or D. I am sorry this is D i; so D i by D 0 this is nothing but 0.56 and assuming this wall temperature to remain constant almost remain constant.

So, we will have a corresponding value for the Nusselt number is equals to 5.56; this can also be obtained from the interpreter blue and David's book. Now here this is nothing, but h D 0 minus D i h D by the k of the fluid. So, we can find out the heat transfer coefficient of the annular space and this comes out to be 38.4 Watt per meter square k.

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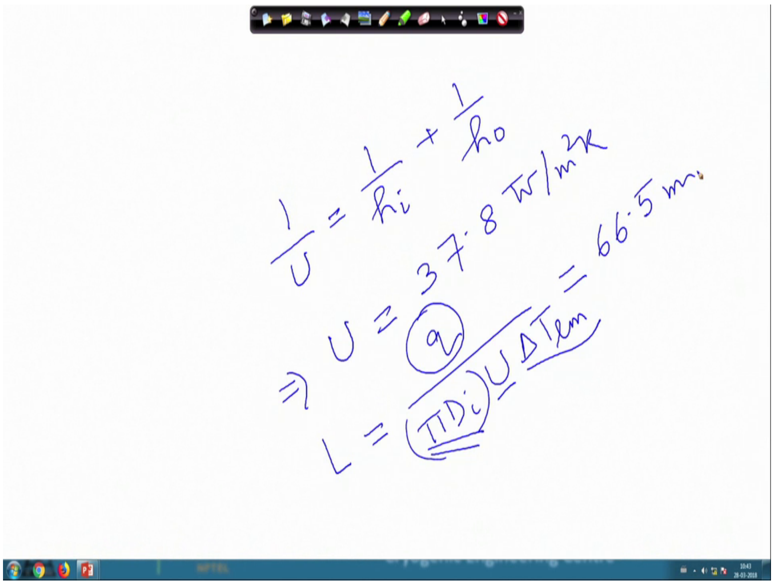

So, once we know the internal heat transfer coefficient and the external heat transfer coefficient. We can now try to find out the overall heat transfer coefficient 1 by is equals to 1 by h i plus 1 by h 0 and that would give you an U off; overall heat transfer conductance to be 37.8 Watt per meter square k.

So, this information will now be used to find out q because 2 pi D I into U into delta T l m where we know q already we have estimated U, we have already calculated delta T l m, we can we this parameter is also known. So, we can find out this length to be 66.5.

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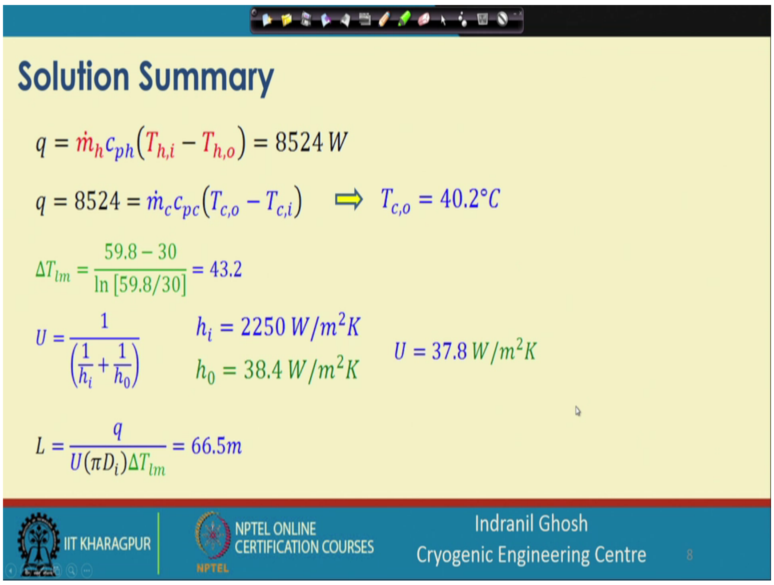

So, in a nutshell if we look at this summary, we find that this is what exactly you have the internal I mean calculations already we have discussed about and we have obtained the length of the heat exchanger to be 66.5 meter.

Thank you.