Heat Exchangers: Fundamentals and Design Analysis

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Lecture – 8
Design and Simulation of Heat Exchangers – Numerical Problem (Contd.)

Welcome to this lecture of Heat Exchanger Fundamental and Design Analysis. Today we are going to solve some numerical problem. This is in continuation to my earlier discussion on the heat exchanger design problem number 1.

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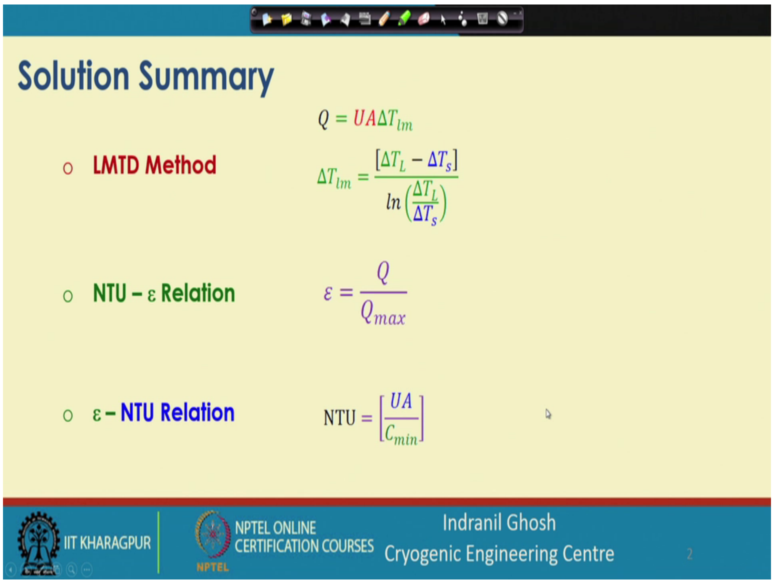

So, in the last class, what we tried to solve is a numerical problem based on the LMTD method. So, we have different we have learned about different techniques LMTD method, NTU epsilon, epsilon NTU relation and now we want to utilize all these techniques to solve different heat exchanger problem and depending on the knowledge of the or the values given for this heat exchanger problem, we have to find out or apply different techniques to solve the different values that we have to get.

So, let us try to solve the problem that we have discussed in the last class.

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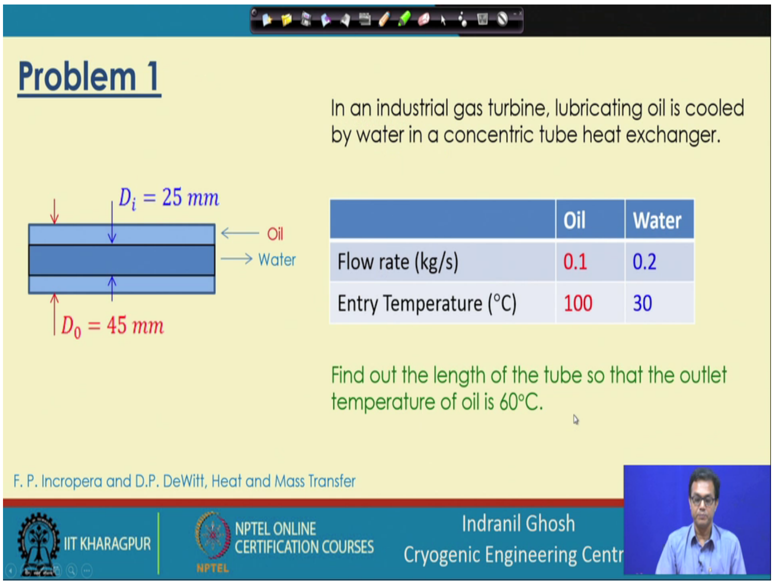

In the last class, we tried to solve this problem where there was an industrial gas turbine heat exchanger and the hot oil was cold by the water in a concentric tube heat exchanger and this were the properties which were given based on this heat exchanger problem.

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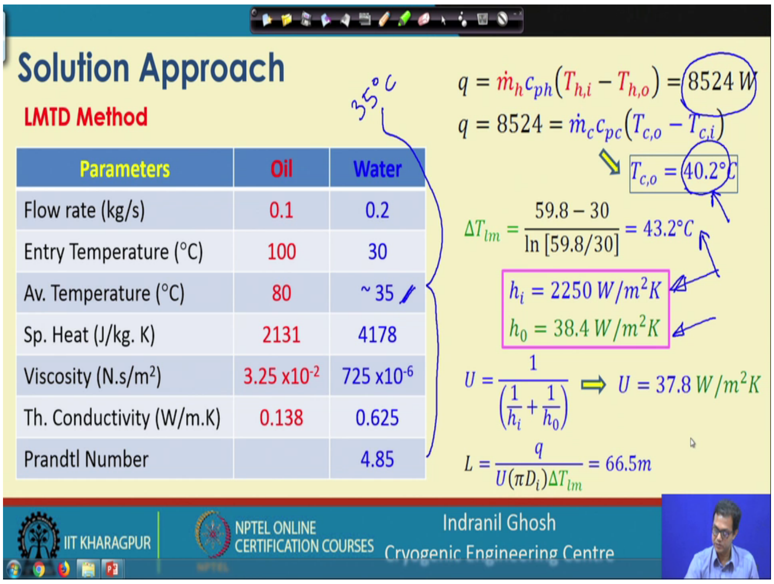

So, we have tried to estimate the overall amount of heat that is getting transferred. So, 8524 watt was the amount of heat that was getting transferred and from there, we try to calculate the cold exit temperature. And thereby, we found that our assumption of the average temperature that 35 degree centigrade. Based on which all these fluid properties were evaluated, we have been able to find out that this is the average temperature, this is the exit temperature and the average temperature is coming to be 35.

So, it was a good guess and based on that, we have solved the delta T lm the overall the log min temperature difference and we had also based on the geometry of the tube, we have been able to find out the internal heat transfer coefficient as well as the external heat transfer coefficient.

Please look into this problem that, in this problem, what was given was the internal diameter and the outside diameter were both given. So, all the unknown parameter was the length of the tube and since the internal and the outside diameter were known to us, we have been able to find out the heat transfer coefficient both internal and exit temperature we have been able to find out. Because, our tube dimensions, the diameter of the tubes were known to us and based on that, we have been able to find out the overall heat transfer coefficient.

So, from there we found the length of the exchanger and it came to be 66.5 meter. It appears to be pretty long and obviously, you can understand that it cannot be a simple straight tube.

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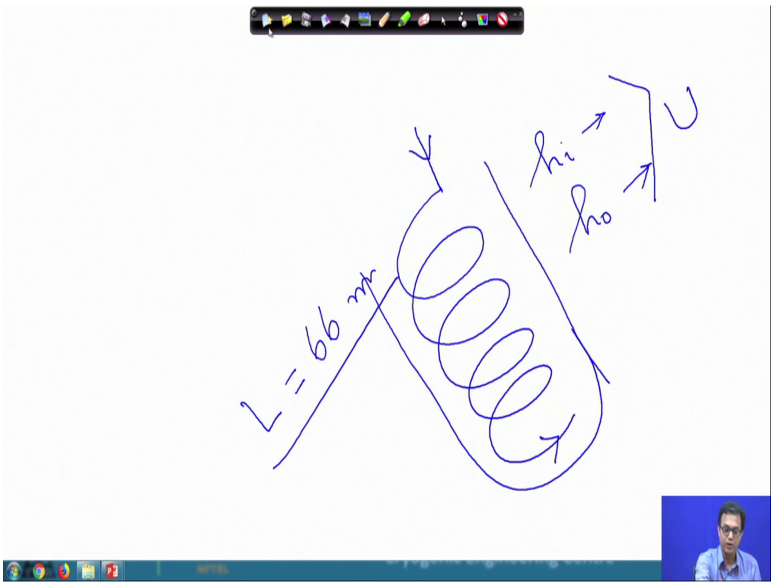

Obviously, we have to make a helix like this or we have to make a coil like this through you know, through that tube. It has to be a concentric tube and you have to make a coil of it and as soon as you make a coil of it, you will find both its internal heat transfer coefficient and the overall I mean outside heat transfer coefficient of the annular space, both will change and that will of course change the overall heat transfer coefficient. So, it will become a different problem. But, we are not going to solve it at this moment. We are only happy with the total length of the exchanger and that he has come to be 66 meter around.

Now, if we go to this mode and we have applied the LMTD technique to solve this particular problem. Now, is there any alternative technique to solve this problem? Let us have a look into that.

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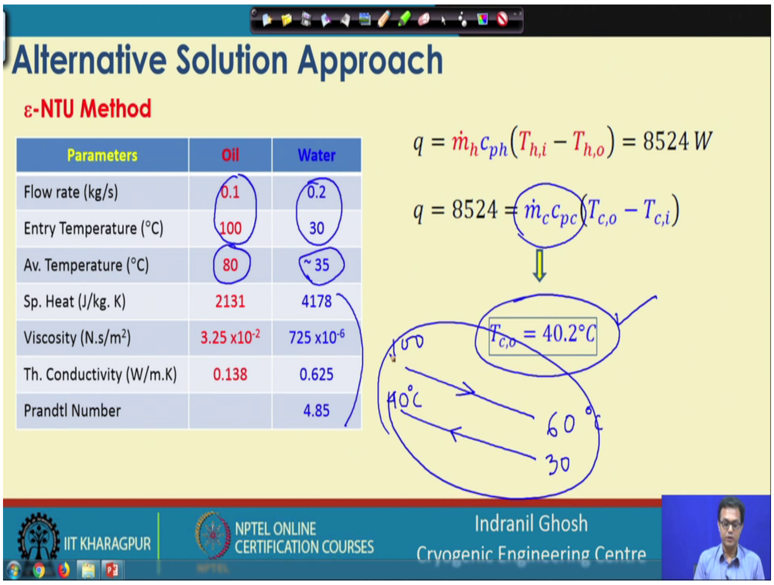

Say, here you we want to apply the epsilon NTU technique. So, what is known to us? What has been given? It is like, you know, in the earlier case we have been given this value the flow rate of oil and water is known to us and the entry temperature of the hot and cold fluid is given.

So, we have been able to find out this average temperature of the oil or the hot fluid because, we know the exit temperature of this oil and it is coming from 100 to 60 degree centigrade and the cold fluid is coming from 30 degree centigrade and it is going out 240 degree centigrade. So, like this, this is the problem statement and as usual, we have assumed some exit temperature for the cold outlet.

So that, we can evaluate all these fluid properties and based on that, we have been able to find out the exit temperature of the cold outlet. It is it has come out to be 40.2 degree centigrade. Now, based on this temperature, now we have all the 4 you see the temperatures known to us and also we know the flow rate and the C p. So, based on this information, if we look at, we will find that we can find out the hot capacity fluid.

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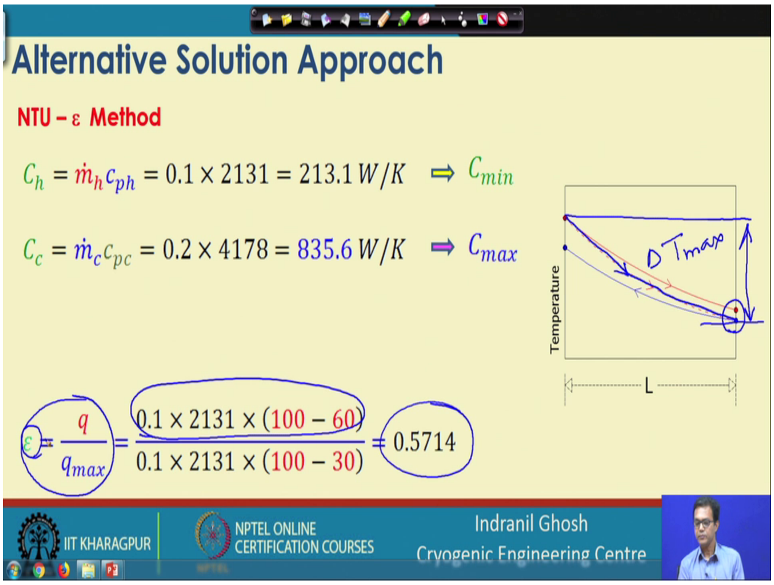

The capacity of the hot fluid and that will come out to be 0.1 multiplied by 2131. So, it is 213.1 and we also have the cold fluid heat capacity so, that will come out to be 0.2 multiplied by 4178 so, that is equals to 835 watt per meter.

So, now we can understand that this is the C minimum, the minimum heat capacity. This is the maximum heat capacity fluid. So, here we have the cold fluid as the maximum heat capacity fluid and the hot fluid is the minimum capacity fluid. So, what would mean is that, what it means is that, the cold fluid you will find that this will come depending on its capacity it can approach this outlet; I mean; the inlet of the hot fluid will reach to the inlet of the cold fluid at the most. So, this is the maximum difference in temperature that can happen or this is the T delta T max; that is possible with the minimum capacity fluid.

So, if we now want to find out the effectiveness of this exchanger, we have to write it in terms of epsilon equals to q by q max and there we can find out it to be this is the heat transfer, actual heat transfer that is taking place; that is, here we have assumed it for the minimum capacity fluid we have written in terms of the that is the minimum capacity fluid is the oil is the minimum capacity fluid and it has come out to be 0.5714 is the epsilon or the heat exchanger effectiveness.

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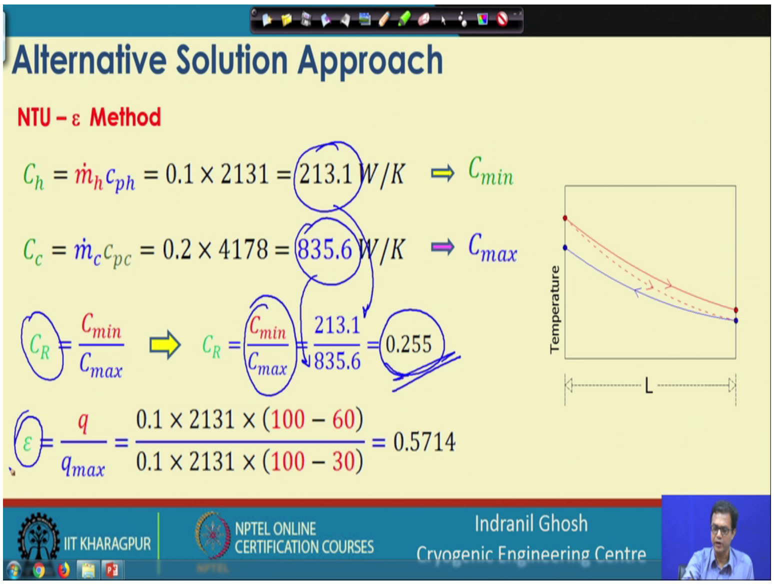

Now, if we find another parameter that is the C min by C max that is equals to C R or the ratio of the to his capacities, the minimum and the maximum and this will come out to be 0.255. That is basically a ratio between this C min and this is ratio between the C min and C max and that will come out to be 0.255. So, here this is the C min, that will come here and this is the C max that will come in the denominator. So, this will give you a ratio of 0.255.

So now, we know C R and we know epsilon. So now, we have to look for a suitable relation that will tell us the NTU.

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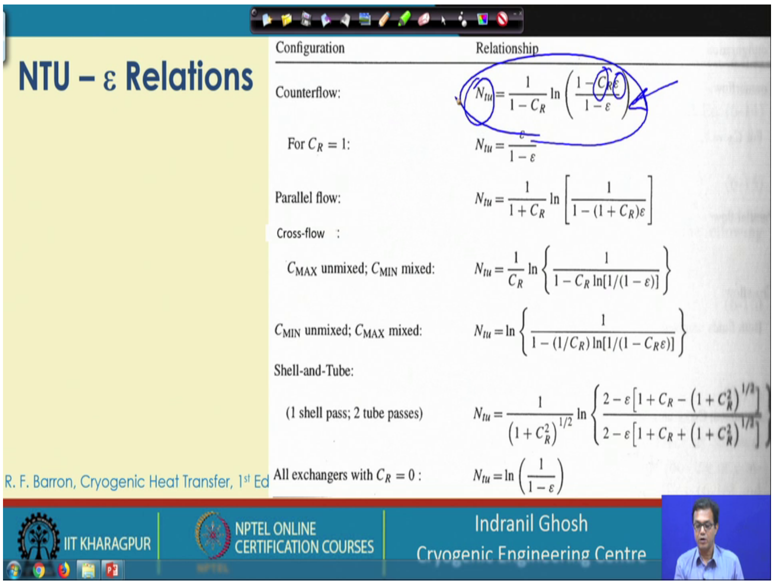

So, this is the counter flow heat exchanger and this counter flow heat exchanger, we know that we have been given something like a relation like this NTU equals to 1 by 1 minus C R ln this part. So, here in this equation, now we see that we know C R, we know the epsilon. So, we can an estimate of the epsilon value. So, this is already known to us. So, this counter flow for this counter flow heat exchanger, we have to use this expression for getting the NTU value.

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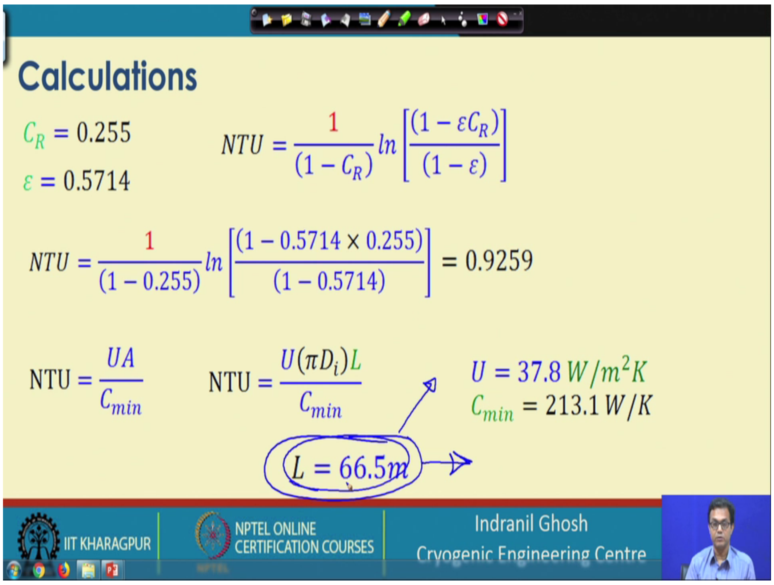

So, with this value of this C R equals to 0.255 and epsilon equals to 0.5714, if we now try to estimate this one, this will come out to be; we put this value and we get 0.9259. So now, we know the NTU and what is the NTU? NTU is basically UA by C min. So, UA we can also write it to be U into pi D i in to l that is, the area. We are looking for through which heat transfer is taking place and you see what are the parameters we know? We know the overall heat transfer coefficient U, overall heat transfer conductance we know C min is known pi D i is known.

So, and NTU already we have been able to estimate. So, we can now so, we have this values of U known, C min is known and we can now try to estimate the L and you will find that length is coming as same as before 66.5 meter.

So, here in this lecture, we are able to find that both the epsilon NTU or LMTD approach is giving the same estimate of the overall heat transfer length which is needed to cool down the oil from 100 degree to 60 degree though it may appear impractical to have so long heat exchangers. But, we find that, this length is necessary to if we have a coaxial tube in tube heat exchanger of given D i and D o. So, this is either of this techniques can be adopted, particularly for this problem. So, we will go into a new problem where we will see the other techniques that can be used for.

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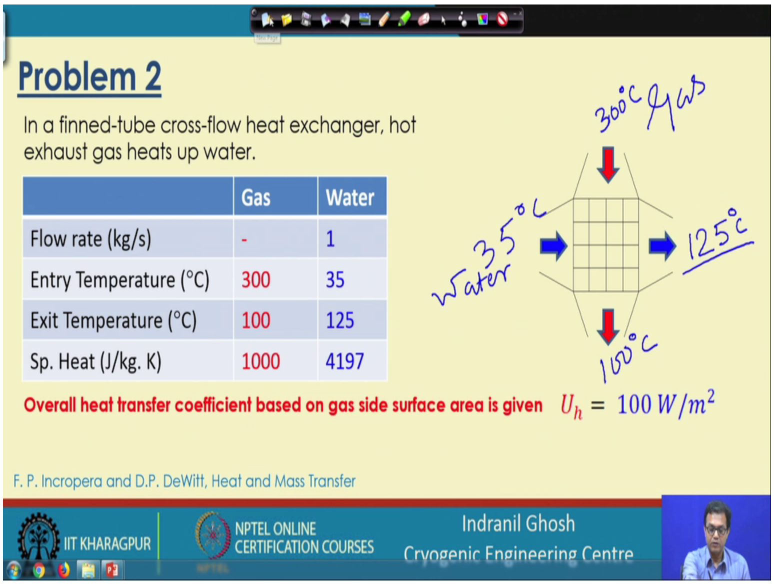

I mean other techniques that we have learnt so far here, there is a heat exchanger that is the cross flow type heat exchanger and it is the finned tube cross flow heat exchanger and no more details has been given and in this exchanger this hot exhaust gas is heating up water and we know this flow rate of the water that is 1 kg per second the entry and exit of both the fluid streams are known. And we have also been told about the specific heat of 2 fluids, because we know both the inlet and exit. So, we know the average temperature and we can as well evaluate the fluid properties at that average temperature.

So, it has already been given. This specific heat of the gas side fluid is 100 1000 joule per kg Kelvin and for the water side, it is 4197 joule per kg Kelvin and the entry and the exit temperature are like this, the hot gas is entering at 300 and getting cool to 100 whereas, the water is getting warmed up from 35 to 125 degree centigrade. So, with this information, if we now look into it, the overall heat transfer coefficient based on the gas side surface area is also known to us and that has been given to be 100 watt per meter square.

So, this is already known to us. As you can understand that we have not been given the details of this finned tube cross flow exchanger, what is the tube side diameter? What is the number of fins to be used? So, instead of telling all those details to find out the internal heat transfer or the external heat transfer coefficient, this overall heat transfer coefficient has already been given to you.

So, what we are supposed to find out is this is like this. We have this is the hot inlet coming here, this is entering at 300 degree centigrade. This is coming out to be at 100 degree centigrade and this is entering at 35 degree centigrade. So, this is water coming in and this is going out at 125 degree centigrade. This is the water outlet and this is what is in the gas going in and out.

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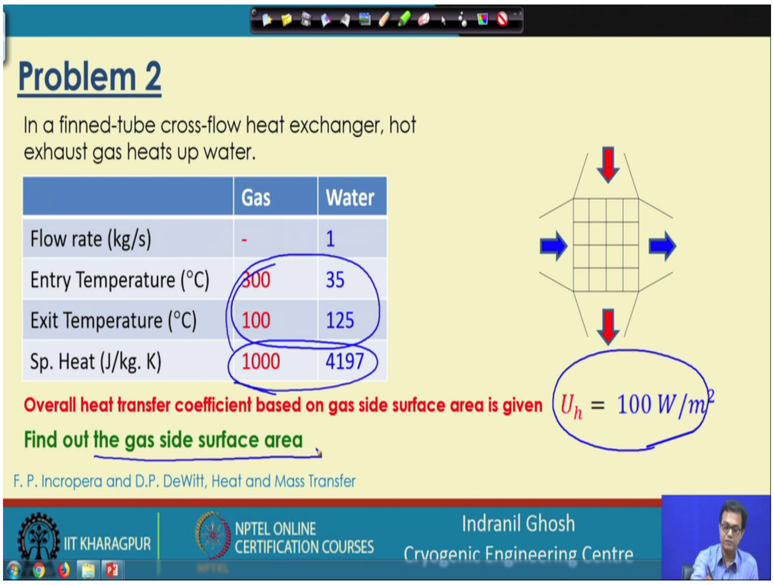

So, what we need to find out is the gas side surface area. So, the problem statement is like this. We have been given the overall heat transfer coefficient, we have all the temperatures known, we have the specific heat known and we need to find out the gas side surface area.

So, for this problem, let us try to see how we can proceed with. So, first of all, if we look at the cold fluid, what is the cold fluid?

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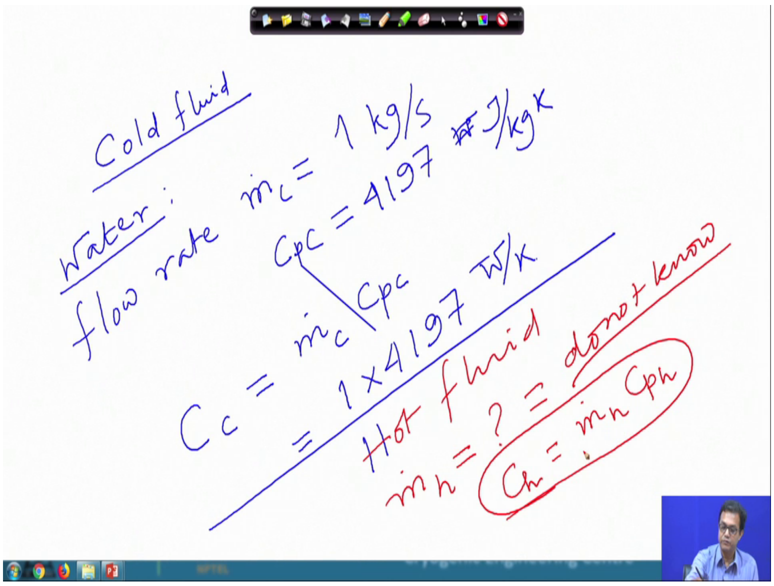

The cold fluid is water. Water is the cold fluid and its properties are known, flow rate is also known. What is the flow rate; m c dot is equals to 1 k g per second what is the C p c? C p c is 4197 joule per kg Kelvin and if we try to find out the C c, the Cold Capacity, that is m c dot multiplied by C p c that will come out to be 1 into 4197 watt per Kelvin.

So, this is one parameter. Then, for the hot fluid, now if we try to find out for the hot fluid, what we will find? This m h dot is not given. We do not know so, we do not know this m h dot, but how to find out C h then? We know C h equals to m h dot C p h and this is what we need to find out.

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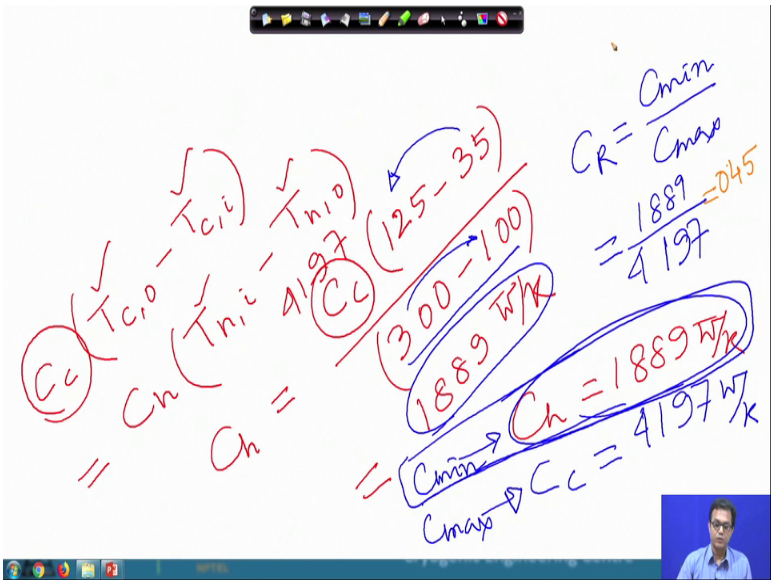

So, for that, we will use another relation where we know that C c multiplied by C out minus T c i is equals to C h T h in minus T h out. So, from this relation, now we look that T c o is known T c i is known all these temperatures are known and also have obtained C c. So, we can find out C h to be C c that is equals to 4197 and multiplied by T c o. T c o is so much 130 125 minus 35 divided by 300 minus T c o is 100 and already we know C c that is equals to 4197. So, this will come out to be 1889 watt per Kelvin.

So now, we have an idea about both C h. So, C h we know it to be 1889 watt per Kelvin and we know C c. C c that is equals to 4197 watt per Kelvin. So, this is the minimum capacity fluid, this is the maximum capacity fluid. So, this is C max and this is C min here. This hot fluid that is experiencing you know that is the minimum capacity fluid. So, it will have the maximum difference in temperature. So, that is also evident that that hot fluid is moving from 300 to 100 whereas, the cold fluid is moving from 35 to 125. So, it is experiencing the hot fluid is experiencing the larger difference in temperature whereas, the cold fluid is experiencing the smaller difference in temperature.

So obviously the fluid which is experiencing more difference in temperature or larger change in temperature so, that will have the minimum heat capacity. So, that is mean we have C R that is equals to C min by C max is equals to 1889 divided by 4197 and that if we evaluate, it will come out to be 0.45. So now, we know C R, we know C min, we can also find out the q.

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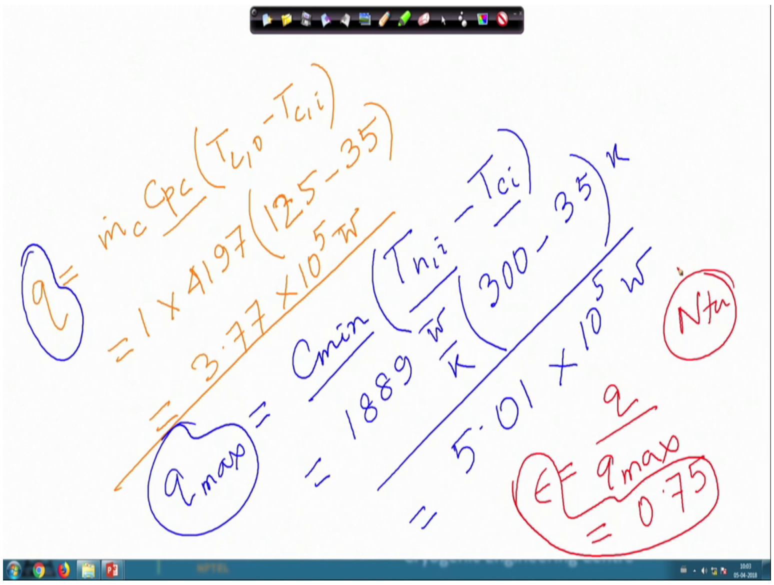

This q will come out to be m dot c that is the actual heat getting transferred C p c, T c out minus T c in, that is equal to 1 kg per second and then we have 4197. Then, we have 125 minus 35. So, this will come out to be 3.77 into 10 to the power 5 watt.

Now, you also need to find out the q max. If we want to find out q max, what is that, how do we know q max? That is equals to C min multiplied by the maximum difference in temperature that can be obtained. So, that is equals to T hot in minus T c in. So, this comes out to be we know the C min. C min we have obtained to be 1889 watt per meter watt per Kelvin and this is T hot in is 300 minus T c i that is equals to 35 degree centigrade.

So, this is the maximum heat that is possible to be transferred and this will come out to be 5.01 into 10 to the power 5 watt. Now, we know the actual heat transfer. We know the maximum heat that can be transferred. So, we can now find out what is the effectiveness. So, this is q by q max and it will come out to be 0.75.

So, when we know the heat transfer coefficient, then so, when we know the effectiveness of the exchanger, now we can use the appropriate correlation where from we can estimate the NTU. So, once we know the NTU, we will be able to find out NTU is given as NTU is UA by C min and we have already been told about the U and C min you have already calculated.

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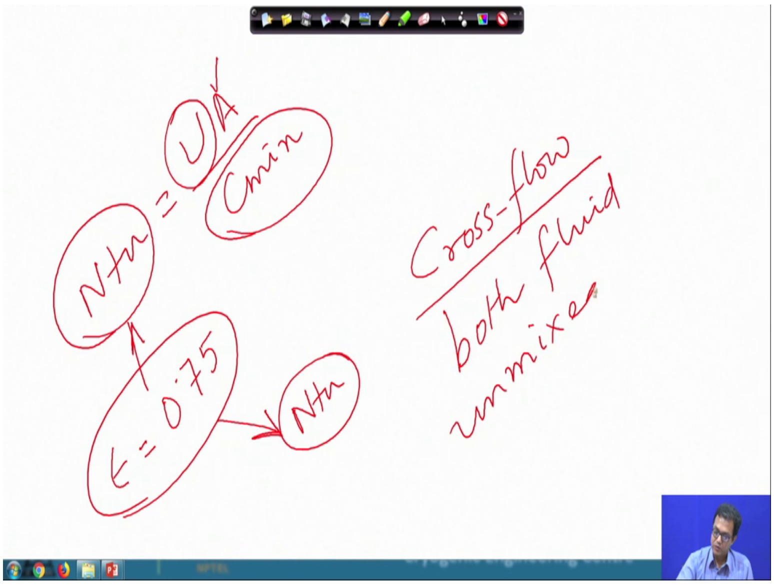

And if we can estimate the NTU, then we will be able to find out the A. Now we already have the knowledge of epsilon to be 0.75. So now, we need to find out the appropriate correlation. You know, for the heat exchanger and we from there, we have to obtain the NTU. Now, we know this exchanger to be a cross flow heat exchanger and there was another information that has been given for this exchanger is that, both the fluids are unmixed fluids, both fluids are unmixed fluid.

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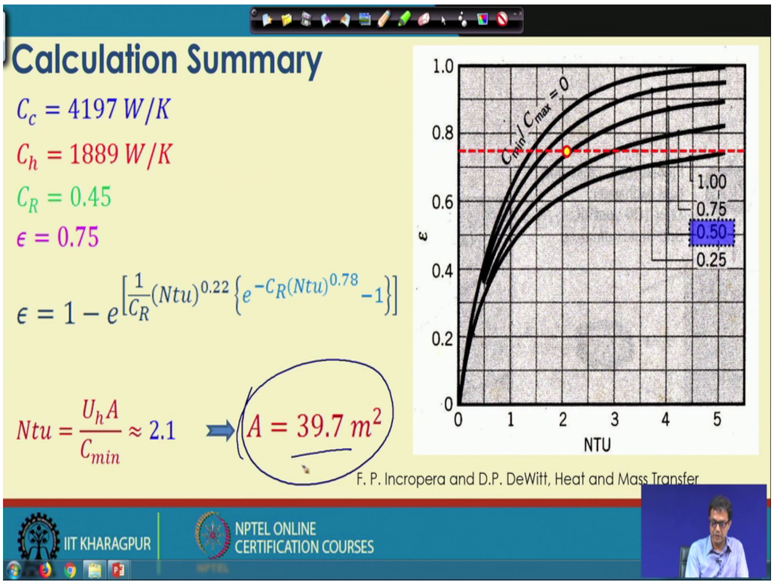

Now, when both the fluids remain unmixed in a cross flow heat exchanger, the effectiveness NTU relation looks like this. The epsilon varies with the power of NTU to the power 0.22 and again inside this one, the NTU to the power 0.78. So, this equation cannot be rearranged to calculate the NTU from the epsilon value. So, but already we have calculated the NTU we have calculated the epsilon. We have the epsilon value known for us, we have the C R value, we have the C minimum value also with us, but we intend to calculate the NTU. But, this relation will directly give you the epsilon not, the NTU.

So, we cannot rearrange this equation also. So, we have to take help of the equation or the graphical solution where we will find that the graphical relation for the epsilon versus NTU. This is the epsilon versus NTU this can be obtained for different C min by C max or C R values ranging from 0 to 1 and this is for C R equals to 0. This is for C R equals to 0.25, C R equals to 0.5 and for us, we have C R equals to 0.45. So, corresponding to that, C R equals to 0.45 and epsilon equals to 0.75 epsilon equals to 0.75, we are finding that the NTU would be somewhere here that is nearly about 0.21.

So, if we consider this to be 0.21, then we have in this equation, U h is known, C min is known and NTU approximately it is 2.1. So, we can calculate the heat transfer surface area and that will come as 39.7. So, the required heat transfer surface area for this heat exchanger is 39.7 meter square.

Thank you.