Fundamentals of Food Process Engineering

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Lecture - 23
Heat Exchangers (Contd.)

Hello everyone, welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering. We were discussing about Heat Exchanger and in our last class we have covered a few topic from this chapter.

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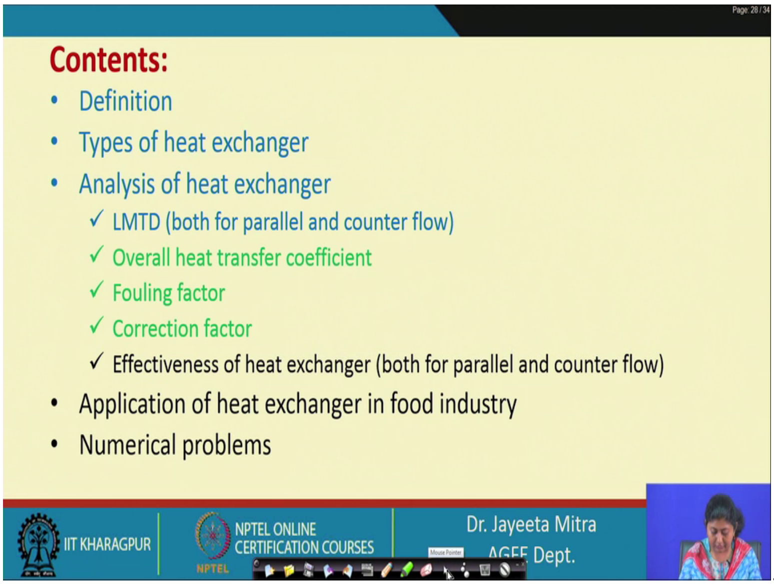

Like types of heat exchanger we have covered, analysis of heat exchanger we have started and in that log mean temperature difference for both parallel flow and counter flow we have discussed and we have derived this for the 2 different cases. Now, today we will discuss the overall heat transfer coefficient fouling factor and correction factor.

So, these 3 terms, the overall heat transfer coefficient is basically very important factor and overall heat transfer coefficient surface area and log mean temperature difference, these 3 are very important for design of any heat exchanger right.

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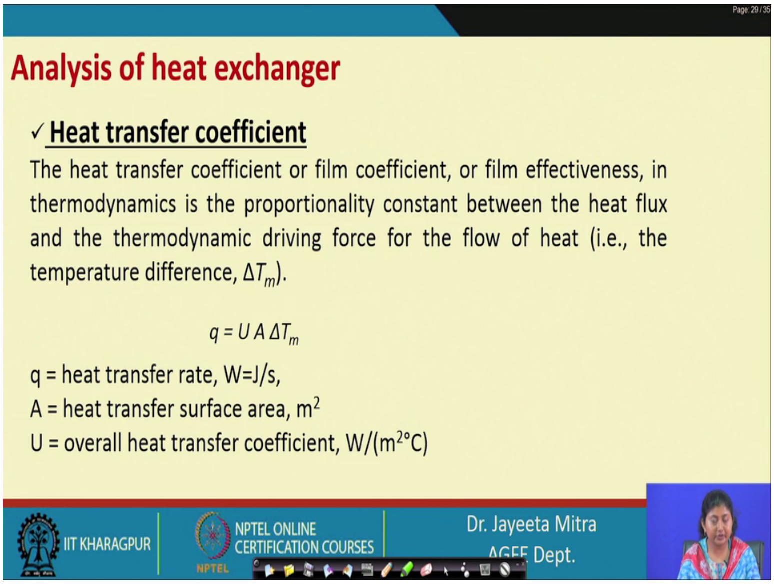

So, let us see how we can define the overall heat transfer coefficient in this case. So, heat transfer coefficient it is can be stated as the heat transfer coefficient or film coefficient or film effectiveness in thermodynamics is the proportionality constant between the heat flux, ok; proportionality constant between the heat flux and the thermodynamic driving force ok.

So, heat flux is q by A, driving force is delta T m and proportionality constant if we remove that we can put here U right. So, this is the concept of heat transfer coefficient ok. So, q is the heat transfer rate, A is the heat transfer surface area. So, rate of heat transfer across unit area that is called the flux; heat flux, U is the overall heat transfer coefficient unit is watt per metre square degree Celsius or watt per metre square degree Kelvin.

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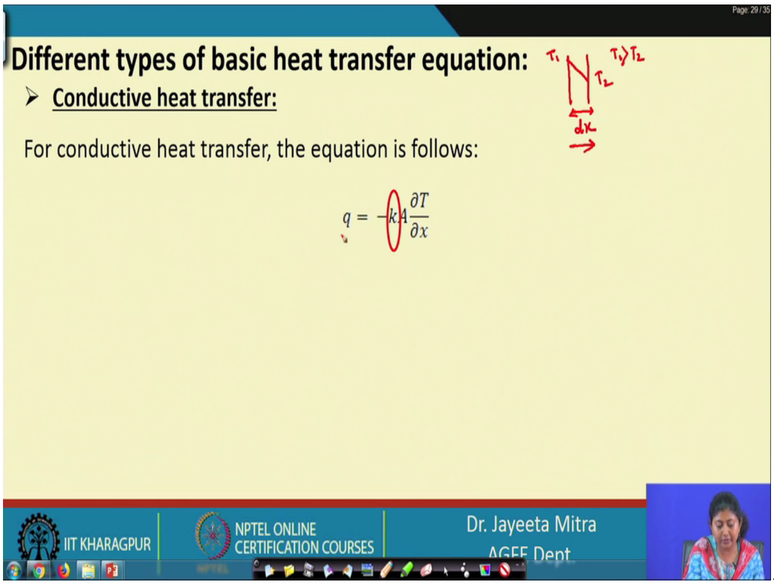

Now, different types of basic heat transfer equation. So, in your heat transfer class you might be gone through the different mode of heat transfer right. So, basically that the 2 very common modes are conduction and convection heat transfer ok. So, convection happens when one fluid and one surface is involved and conduction is when only heat is transferred through a solid surface or solid wall like that. So, conductive heat transfer if we consider, the equation will be this way that is q equal to minus k A d T by d x.

So, we can think of this way like if this is a solid wall having d x thickness and the heat is flowing from the higher side to the lower side where, T 1 greater than T 2. Since heat is flowing down from the higher to lower side in the direction of positive x that is why we are putting a minus here. So, q equal to minus k A d T by d x ok.

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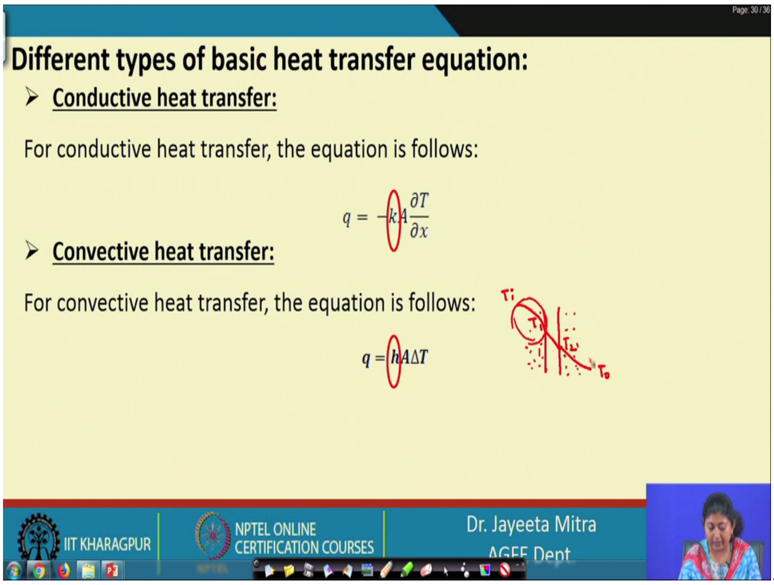

And if we say the convective heat transfer, so, the equation of convective heat transfer will be q equal to h A delta T.

So, this is involved when suppose we have a wall, where this conduction is happening and this is a temperature T 1, this is T 2. However, there is a air layer or for that matter any fluid which is flowing pass the surface. So, here we can get a temperature gradient; here it is T i and this is T o if it happens. So, the heat transfer happen in this zone; in this zone that is because of convection. So, from the fluid to the wall it is going ok.

So, this is called the convective heat transfer coefficient, we can have this convective heat transfer coefficient in both the side, in and out we can term it term it as h i in the inlet side and h o in the exit side right. So, this is convective heat transfer coefficient h.

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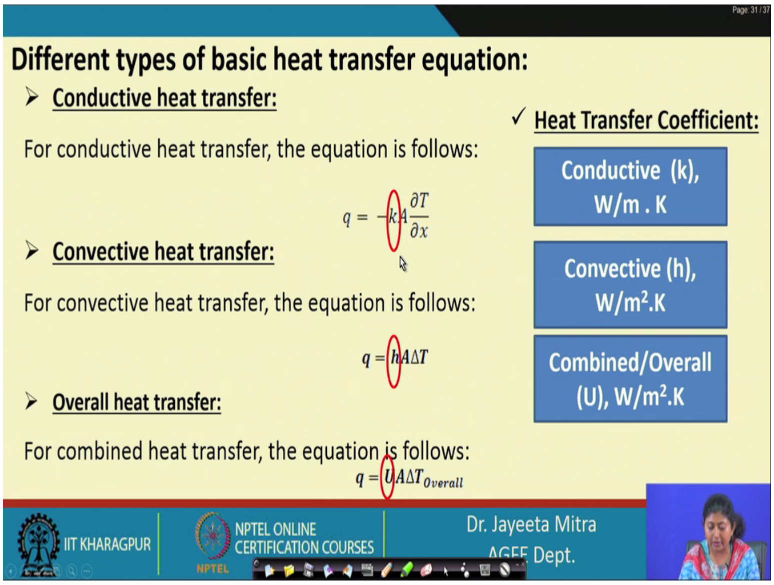

So, overall heat transfer coefficient. So, when we deal a practical case for example, in this case of heat exchanger, we are talking about 2 fluid and 2 fluids are separated by a wall surface heat exchange surface or a wall so; that means, the fluid has the convective heat transfer coefficient in both the side of the wall, and they has to cross the heat you know flow of heat has to cross the wall of the heat exchange surface as well.

So, here we need both conduction and convection together and combine them to find out the overall heat transfer coefficient ok. So, q equal to U A delta T overall. So, heat transfer coefficient when we say conductivity conductive heat transfer coefficient k. So, that is unit watt per meter kelvin convective heat transfer coefficient h unit is watt per meter square kelvin or watt per meter square degree celsius and when we see combine or overall heat transfer coefficient that includes h and k both. So, that is termed as watt per meter square kelvin or watt per meter square degree celsius ok.

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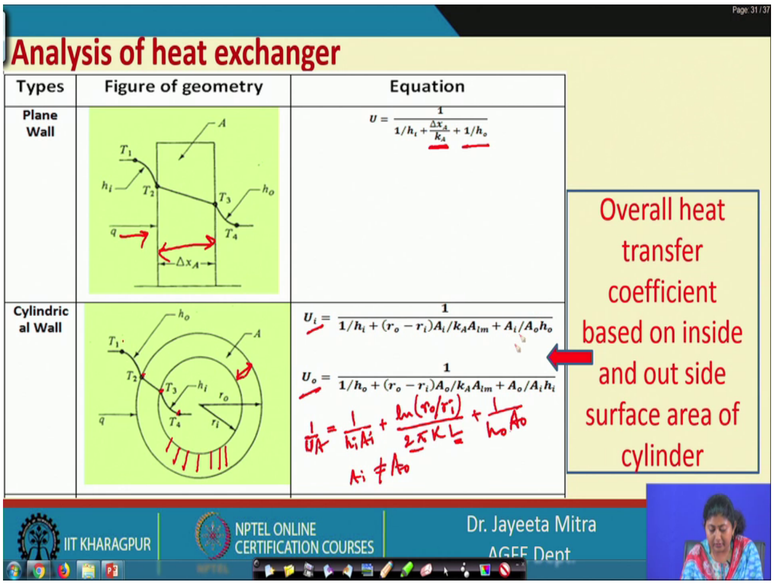

So, now we will see the common configuration that we most often encounter in heat exchanger those are. First is if there is a flat plate having any kind of you know solid material, delta x A is the thickness and the fluid in one side there is a hot fluid and the other side there is a cold fluid. So, that is the configuration of a heat exchanger normally. Heat q is coming from the high temperature side to the low temperature side, T 1 is the temperature in the hot fluid T 2 is the temperature at the surface of the wall outer surface of the wall, T 3 is the temperature of the inner surface of the wall and T 4 is the temperature in the cold fluid section.

So, overall heat transfer coefficient we can express as U that is equal to 1 divided by 1 by h i plus delta x A by k A plus 1 by h o. So, this is actually if we talk about we know that you know to cause any flow we need driving force divided by the resistance term right. So, here when in this side where the hot fluid is there, in this side h i is the heat transfer coefficient heat transfer coefficient.

So, 1 by h i is actually the resistance in that side hot fluid side, then delta x A by k A this is the resistance in the solid wall or the surface. And 1 by h o this is the resistance in the cold fluid side, h o is the heat transfer coefficient convective heat transfer coefficient and 1 by h o is the resistance ok. So, combining all the resistance in series that we encounter here and 1 by resistance that is here overall convective overall heat transfer coefficient.

Now, we have taken here delta x A by k A because the heat has to flow this thickness delta x A and where the conductivity of the material is k A. But if we are handling cylindrical wall for that matter concentric tube are there in a heat exchanger. So, inside there is a fluid and outside there is another fluid and this is the wall ok.

So, this is the wall of a pipe. So, if the higher hot high temperature fluid is outside let us say T 1 is the temperature. So, T 1 to T 2 that is the outside surface of the tube, then it is conducting through the wall and T 3 is the inner surface of the tube and T 4 is the fluid which is in the central tube ok. So, here we can define the overall heat transfer coefficient ok.

So, generally we define it i can write it here like 1 by U A that is equal to 1 by h i A i plus l n r o by r i divided by 2 pi K L plus 1 by h o A o. So, in such a case where A is very you know A is equal. So, when A can be equal, if this thickness of the tube is very small or if this wall when we have considered this if it is very small. So, in that case we can consider that we can consider that this area inside area that is A i will be very much equal to A o and that is equal to A ok.

So, in that case we can omit this, I mean a i h o and this equation will just become this and from here we can find out what is U ok. So, U will be one divided by this whole value. So, we can get that. Now if it is not equal if you know A i is not equal to A o that is there is a significant thickness of the heat exchange surface is there, that time we can either define the overall heat transfer coefficient based on inside surface area or we can express them based on the outside surface area.

So, if we want to express them based on the inside surface because it was U A h i A i and h o A o like that. So, in that case we will multiply that with A i in both the side. So, we will get we will get here 1 by h i plus r o minus r i by A i divided by k A into a l m a l m is nothing, but the log mean surface area that is A 2 minus A 1 by l n of A 2 by A 1 and A 2 is the a whole surface area that is 2 pi r o into l minus A 1that will be 2 pi r i into l and here also this area A 2 minus A 1 that has been i mean 2 pi l has been cancelled from this 2 pi l. So, only r 2 r o minus r i remain and divided by k into a l m and similarly A i divided by A o h o.

Now, if we you know want to express it based on the outside surface area. So, that time we will multiply this 1 by h i A i plus r o minus r i into A o 1 divided by k A a l m into A o will be cancelled. So, this side 1 by h o will be there and here 1 into A o by A i h i will be there ok. So, if the thickness of the heat exchange surface is very less, we can consider that the inside and outside surface area are equal and that time we need not to take all this we simply can have 1 by h o plus the l n of r o by r i as I as I said.

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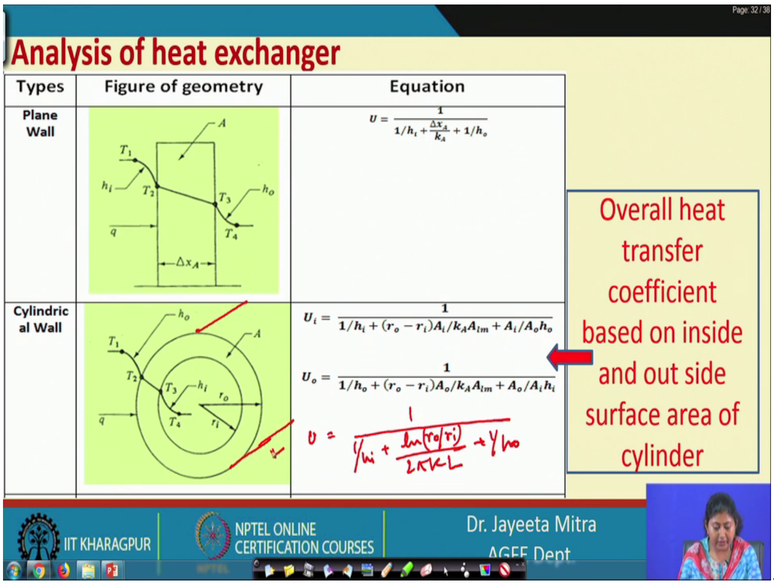

That u will be then 1 by 1 by h i plus l n of r o by r i divided by 2 pi k L, L is the length of the tube plus 1 by h o ok. So, if we extend this.

So, the length will be L right. So, this is how we can calculate the overall heat transfer coefficient and also you can think of that it depends on what is the convective heat transfer coefficient value, based on that your overall heat transfer coefficient can be defined. For example, if you have in the hot fluid side let us see for this case in the hot fluid side you have h i.

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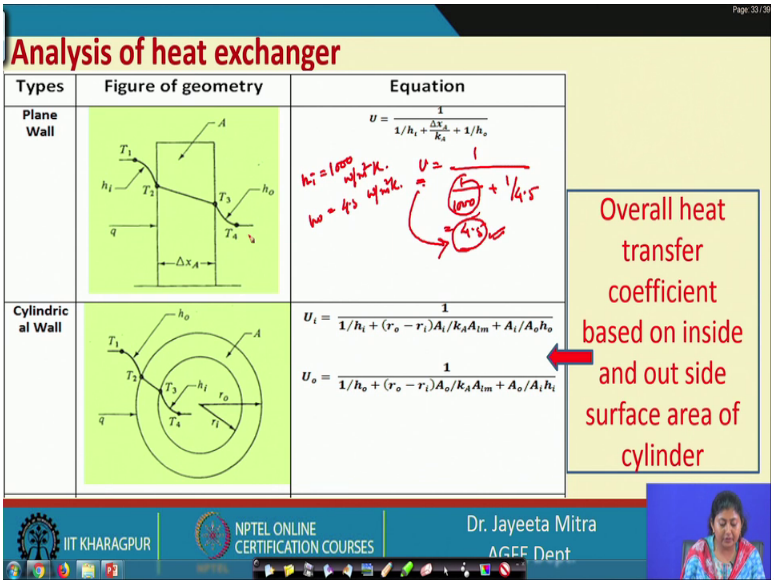

So, h i let us say 1000 watt per meter square kelvin and in the cold fluid side h o you have a small value let us say 4.5 watt per meter square Kelvin and if we consider for example, the delta x is very small. So, if delta x is very small. So, delta x by k this term will be negligible, the resistance offered by this section will be negligible similarly if it happens for the tube also the middle term will be negligible.

So, in that case your U will be 1 divided by 1000 plus 1 divided by 4.5right. So, again you can you can see that this 1 by 1000. So, the value is very less. So, you can neglect this as well. So, one by one that is ultimately coming 4.5 so; that means, overall heat transfer coefficient is mostly close to your lower convective heat transfer coefficient value.

So, in this kind of you know overall heat transfer coefficient if you are you are having and if you take this as well if you take this as well I mean the value you consider without neglecting then also you will getting close to this, not very different value you will get right. So, a little bit lower than 4.5 you will get right.

So, that that is why we can understand that if such kind of a problem is given to you where thickness is very less you can almost neglect that one, and higher side heat transfer coefficient and in the in the other fluid where the heat transfer coefficient is very low, your overall heat transfer coefficient will always be close to the lower side ok. So, this is one you know explanation how you can characterize different cases.

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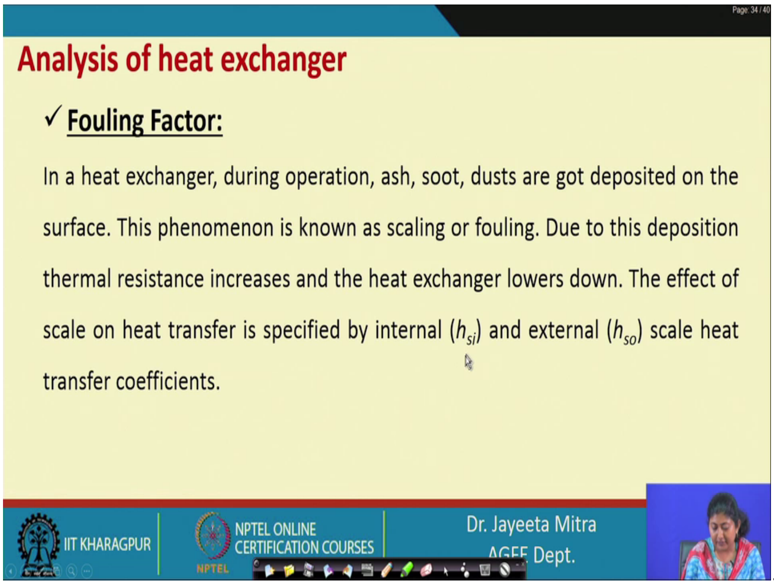

Now, fouling factor; fouling factor is very important one and it does effect sometime the efficiency of heat exchanger because what happen you know, when we are dealing with different kind of fluid there are certain you know dissolved material are there in the fluid which is get deposited in the inner side of the tube ok. And if it deposited there it will eventually lower the heat transfer rate ok.

So, it will offer a resistance like the surface is providing a resistance, the thickness is thickness or the conductivity of the material is providing resistance similarly when they form skill, they will offer a resistance. So, that is the inside one and in the exit or the or the open side as well, there may be some deposition happened because of that dust ash all those thing got deposited on the outer surface and there also skill formation or because of this dirt and dust their efficiency, gets lowered ok.

So, inner heat exchanger during operation ash shoot dust are got deposited on the surface, this phenomena is known as skilling fouling. Due to this deposition thermal resistance increases and the heat exchanger lowers down. The effect of scale on heat heat transfer is specified by internal and external scale heat transfer coefficient ok.

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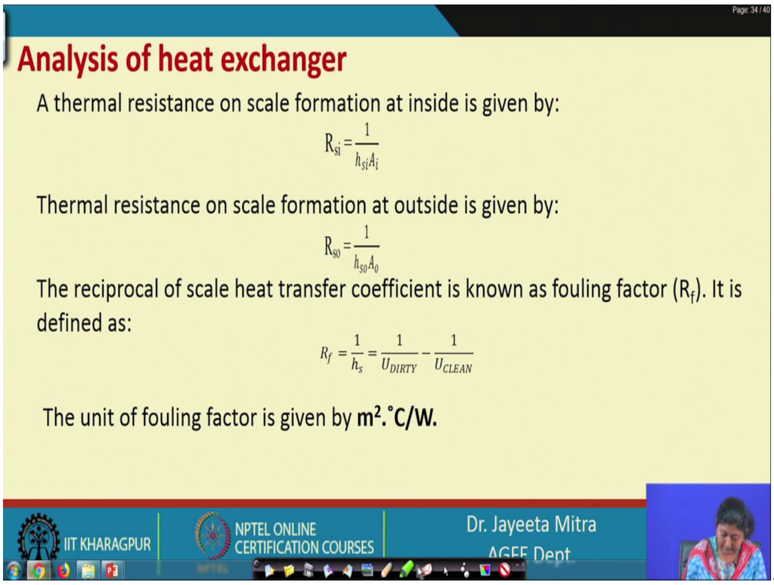

So, h s i is a sorry h s i is the heat transfer coefficient, h s i is the heat transfer coefficient for inside scale deposition, h o is the heat transfer coefficient because of the exit or the opposite side or open side external side heat transfer coefficient and from this we can easily calculate the resistance like 1 by h s i A i and 1 by h s o a o ok. So, the thermal resistance, the thermal resistance on scale formation inside that is R s i.

So, that will be h s i into A i; h s i was the heat transfer coefficient in the in the scale side inside of this scale deposition. So, resistance will be 1 by convective heat transfer into A i. Similarly for the outside or external side R s o will be the resistance and the value will be 1 by h s o into A o.

So, the reciprocal of scale heat transfer coefficient is known as fouling factor R f ok. So, R f fouling factor R f is 1 by h s that is 1 by U dirty that is overall heat transfer coefficient, when the system is dirty and 1 minus 1 by U clean. That is overall heat transfer coefficient of the system, when the deposition where not there. So obviously, U clean will be higher than U dirty. So, we are getting a positive value that is the value of the fouling factor. The unit of fouling factor is given by meter square degree celsius per watt.

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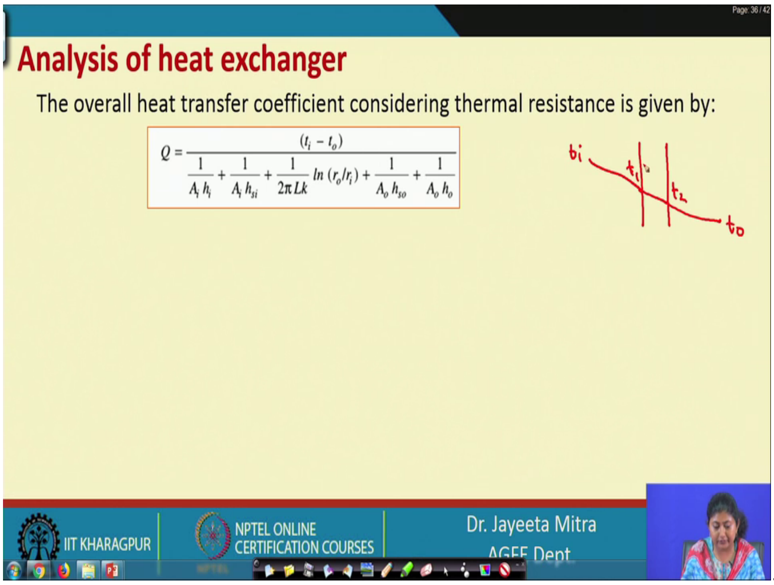

So, the overall heat transfer coefficient considering the thermal resistance is given by Q, overall heat transfer coefficient that is equal to driving force that is t i minus t o; because if you remember that if it is tubular one or flat one we have t i and then there is T 1 then there is T 2 and finally, we are getting t o ok. So, the total temperature difference the total gradient we are having that is t i minus t o divided by 1 by A i h i that is the fluid side external resistance 1 by A i h i plus 1 by A i h s i that is the. So, this is the inside one this is the inside resistance for the fluid, this is the resistance because of inside scale deposition and this is because of the layer of the tube or the or the surface of the tube because that is the conductive resistance will be provided there, then this is the outside scale deposition and this is the resistance because of the outside fluid ok.

So, driving force by resistance this will be the overall heat transfer.

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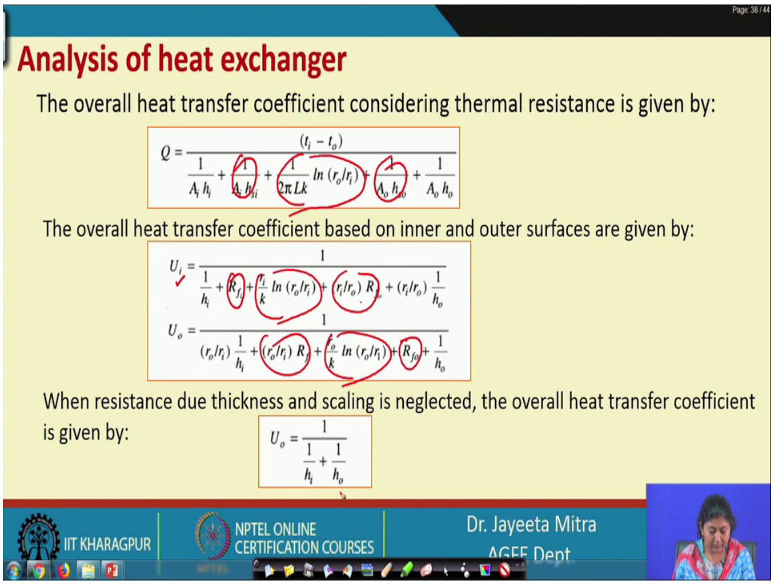

And the overall heat transfer coefficient based on the inner and outer surface if we again specify as we did in earlier case. So, we can write in this way 1 by h i this is based on the inside surface area. So, overall heat transfer coefficient will be 1 by 1 by h i plus R f i the resistance because of the inside deposition, r i by k into l n r o by r i plus r i by r o into R f o because this is again done based on the outside surface area plus r i by r o 1 by h o and if it is done on the basis of outside surface area. So, r o by r i into 1 by h i plus r o by r i r f i because this is based on the overall. So, the reverse of this we are getting then plus r o by k into l n r o by r i plus R f o plus 1 by h o.

So, when resistance due to thickness and scaling is neglected, the overall heat transfer coefficient is given by this value. Because resistance due to thickness and scaling both are neglected. So, because the thickness part we can we can neglect this term this term here this one and here this one. So, when thickness is neglected. So, we are getting this term out of the equation and the scaling. So, scaling. So, because of scaling we are not getting this term and this term R f o and R f i. So, we will end up with this 2 term 1 by h i plus 1 by h o. And again in this case also we can analyse which one is higher h 1 or h o. So, that will help us to analyse what will be the value.

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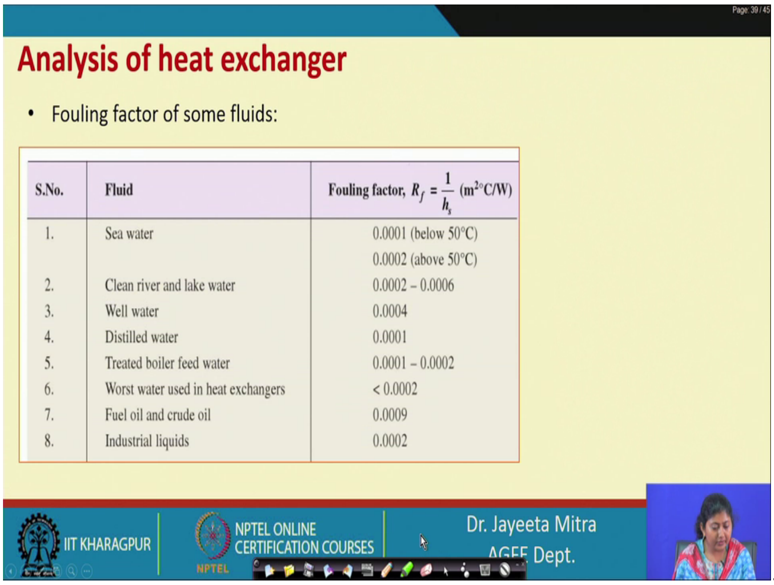

So, fouling factor of some fluids this you may get in many textbook and you can observe that, what are the range of this fouling factor R f that is in meter square degree celsius per watt. Like in for the distilled water this is 0.0001, for the treated boiler feed water that is ranging from 0.0001 to 0.0002, fuel oil and crude oil this is 0.0009, industrial liquid 0.0002, etcetera.

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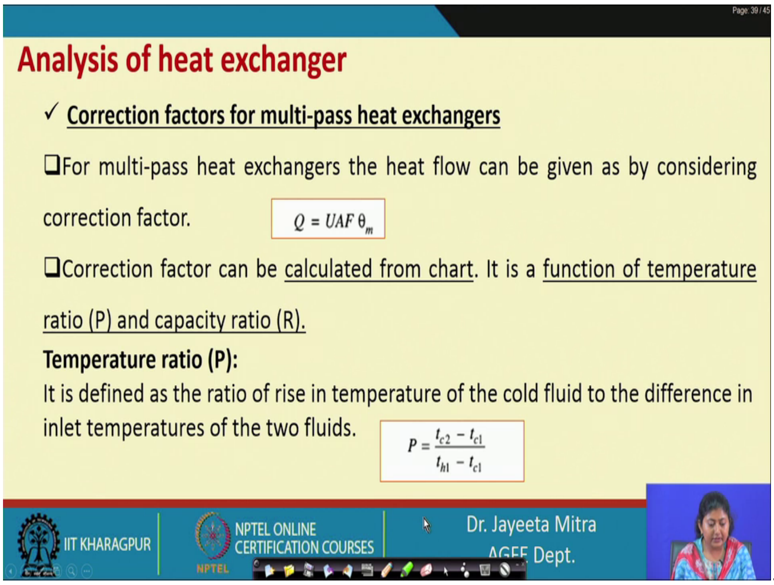

Now, another thing is correction factor for multi pass heat exchanger. So, you might be remembering that multi pass heat exchanger we mostly use this one in shell and tube cases, where one shell pass 2 tube pass or 2 shell pass four tube pass and different configuration we handle. So, there are multi pass is being done and we often introduce a correction factor that is called F ok. So, correction factor can be calculated from a chart, it is a function of temperature ratio p and capacity ratio r ok, so, temperature ratio p and capacity ratio.

So, let us see first what is the temperature ratio and what is capacity ratio. Temperature ratio is defined as the ratio of rise in temperature of the cold fluid to the difference in inlet temperature of the 2 fluids. So, rise in temperature of the cold fluid t c 2 minus t c 1 right and the inlet temperature of these 2 the difference is t h 1 minus t c 1.

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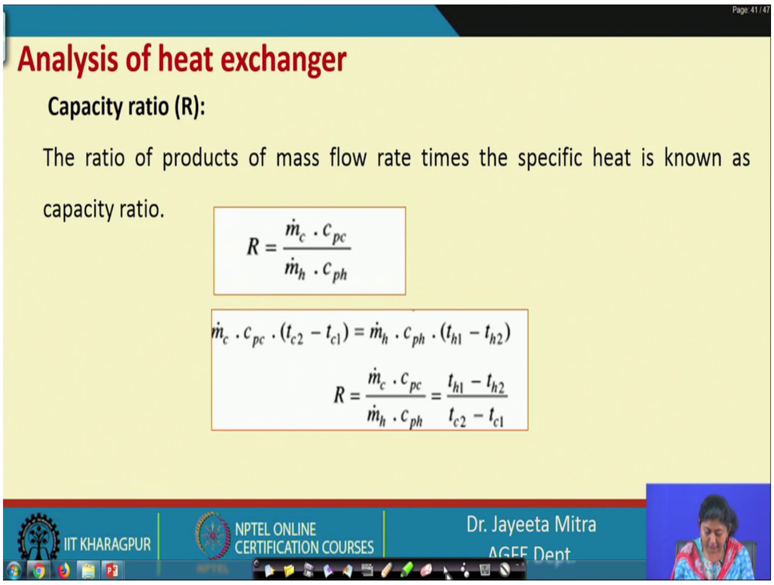

So, this is the temperature ratio. And let us see what is the capacity ratio? So, capacity ratio by name you can guess that it is the ratio of how much amount of cold fluid and how much amount of hot fluid taking part and what are their relative c p or specific heat; that means, basically the heat capacity of both the fluids are taken here.

So, the ratio of products of mass flow rate times the specific heat is known as the capacity ratio R. So, heat capacity of the cold fluid divided by the heat capacity of the hot fluid ok. And in terms of temperature how we can define this? So, we know that the mass flow rate of the cold fluid into c p of the cold fluid into t c 2 minus t c 1 this will be equal to mass flow rate of the hot fluid into c p h into t h one minus t h 2 ok.

So, then r will be m c into c p c divided by m h into c p h that is equal to t h 1 minus t h 2 that is the difference in the hot fluid divided by t c 2 minus t c 1 difference in the cold fluid. So, we are getting 2 things temperature ratio and capacity ratio and using these 2 we will see what will be the correction factor.

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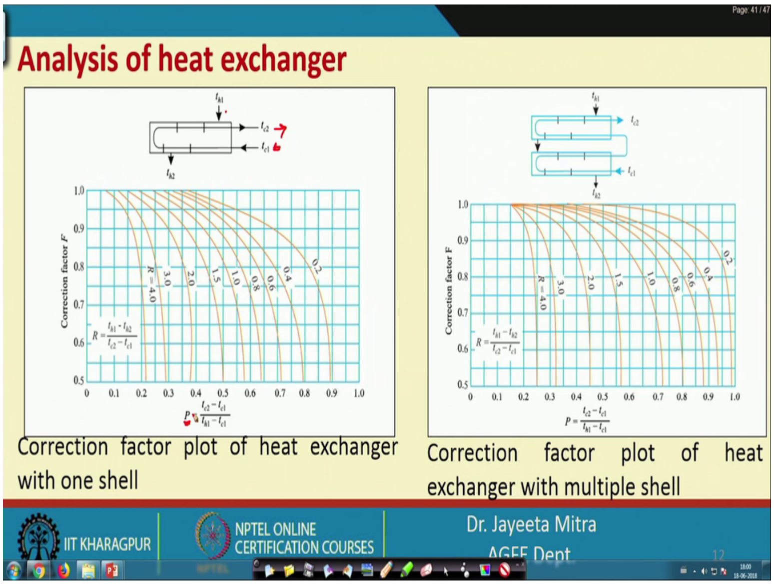

So, first case; here we have one shell pass 2 tube pass the configuration is 1, correction factor plot of heat exchanger with one shell ok. So, here we are getting 1 shell pass 2 tube pass. So, t c 1 is entering and t c 2; t c 1 is entering and t c 2 is coming out and t h 1, it is entering in a cross flow situation t h 2 is coming out. So, p value ok. So, we have calculated that is difference in the cold fluid temperature divided by inlet of hot and cold that we have calculated and another is the capacity ratio r we have calculated ok.

So, from these 2 data we can calculate the correction factor. So, let us say for p is 0.4 and 1.5 will be the capacity ratio. So, this point when it heat, so, corresponding to that value. So, something 0.86 or so will be the value of correction factor. Similarly, correction factor for a plot of heat exchanger with multiple shell. So, this is 2 shell pass 4 tube pass right. So, in this case also we can the charts are available. So, we can similar fashion we can calculate the p value and r value and from the chart we can find what will be the correction factor. So, this correction factor will include in our equation that is U A delta t m and then we can calculate the exact amount of heat transfer. So, we will stop here.

Thank you.