Fundamentals of Food Process Engineering
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Lecture - 24
Heat Exchangers (Contd.)

Hello everyone, welcome to NPTEL online certification course on Fundamentals of Food Process Engineering; we are discussing now Heat Exchanger ok.

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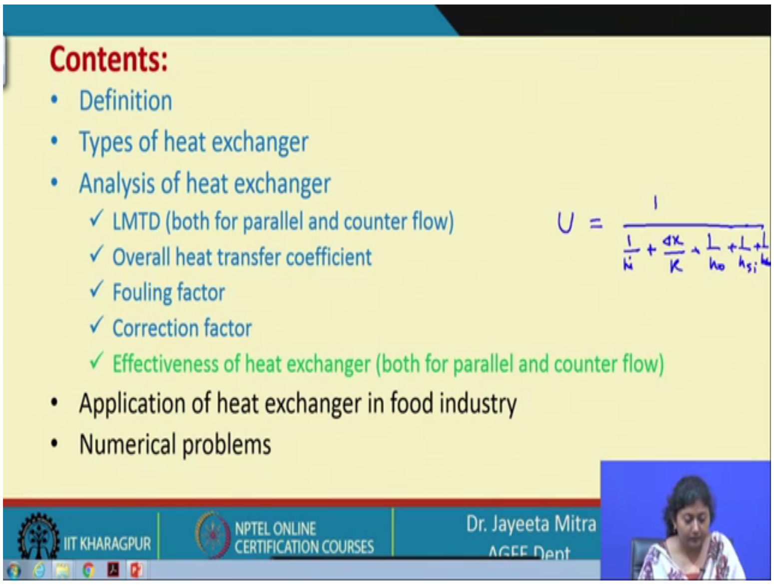

So; we have already covered few topics including the definition, types of heat exchanger, then we have discussed the analysis of heat exchanger. In the analysis we have discussed Log Mean Temperature Difference: LMTD for both parallel flow and counter flow. So, if you remember the log mean temperature difference we generally, you know express this as theta m or delta T m or some book you may find this as delta T L m. So, its value is theta 2 minus theta 1 by l n theta 2 by theta 1 right and you just have to remember that what will be the value of theta 1 and theta 2 because if it is you know the parallel flow ok.

So, across the area if you are; if you are drawing the temperature profile of both the fluid hot and cold; so theta 1 will be this one and theta 2 will be at the end, whatever gap we are getting temperature difference we are getting. And if it is parallel flow this is for the parallel flow and if we are discussing counter flow then so this is the direction of the hot fluid and this is the direction of the cold fluid and if we are getting theta 1 here and theta 2 here. So, this will be t h 1 t h 2 and this is t c 1 and this is t c 2 right where the here in the first case parallel flow, this is t c 1 to t c 2 and this is t h 1 to t h 2 right. So, in the counter flow case theta 1 will be t h 1 minus t c 2 and theta 2 will be t h 2 minus t c 1. So, this we have discussed in our previous classes on heat transfer, we have also discussed the overall heat transfer coefficient. So, if you remember the overall heat transfer coefficient that is U.

So, U has been derived by this expression that is when area is same in that case we can express this by this fashion, if it is for a plate otherwise we need to consider the equation for a cylinder if it is a tube that is l n of r o by r i divided by 2 pi K l, where l is the length of the tube and h i is the inner side heat transfer coefficient convective heat transfer coefficient and h o is the outside convective heat transfer coefficient right. Now when we discuss the fouling factor then with this the factors of fouling resistance of fouling for the inside and outside that will come so 1 by h s i plus 1 by h s o.

So, this has been done when area is same, if area is not same we need to consider area in this equation that we have already discussed. And then we have also discussed the correction factor that depends on the various configuration of shell and tube heat exchanger that is number of tube passes and this for this we have calculated the temperature ratio and capacity ratio, temperature factor and capacity ratio and from those two using the chart we have we have determined the values of correction factor.

Now, today we will going to learn a very important concept in case of heat exchanger that is effectiveness, again we will discuss for both parallel flow and counter flow. After that we will discuss the application of heat exchanger in food industry, that is what are the various kinds of various types of heat exchanger that are commonly used. And we will solve a numerical problem ok.

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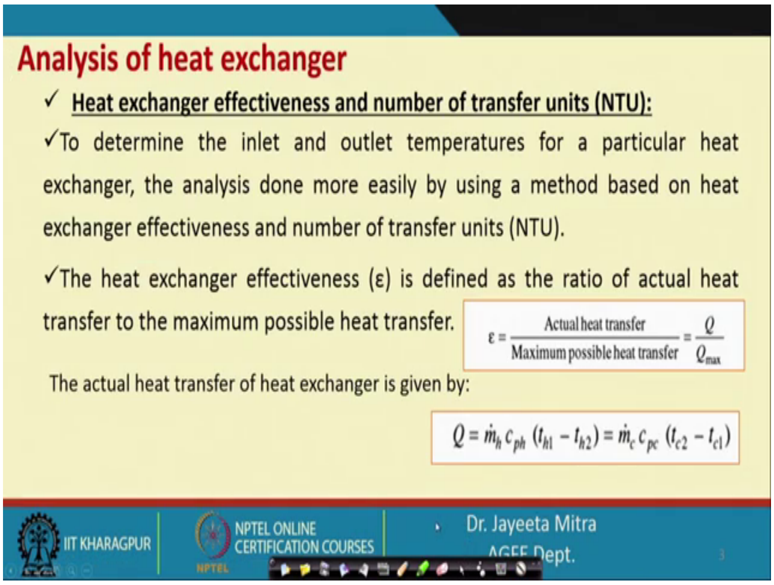

So, now heat exchanger effectiveness and number of transfer units. So, effectiveness is very important; this in the general terms if you analyze the effectiveness; that means, that what is the maximum possible effect or heat transfer that we can get out of the heat exchanger ok. So, in this case we need to look that what is the actual heat transfer happening and what the maximum heat transfer can be done and the ratio of these will be termed as effectiveness.

So, determine the inlet and outlet temperatures for a particular heat exchanger, the analysis done more easily by using a method based on heat exchanger effectiveness and number of transfer unit. So, the effectiveness is defined as the ratio of actual heat transfer to the maximum possible heat transfer. So, actual heat transfer means the heat transfer from the hot fluid to the cold fluid that we are getting; that means, the m c p delta t for the hot fluid or m c p delta t for the cold fluid ok. So, effectiveness epsilon that is equal to actual heat transfer by maximum possible heat transfer so Q by Q max.

Now, the actual heat transfer of heat exchanger is given by as I said flow rate hot fluid m h dot c p h specific heat of hot fluid; so together this constitute the heat capacity of the hot fluid into temperature drop that is t h 1 minus t h 2 and this heat is taken by the cold fluid, so mass flow rate m c dot into c p c specific heat of the cold fluid and temperature it has increase on t c 1 to t c 2. So, t c 2 minus t c 1 this will be the value here for the change of temperature so, this is the actual amount of heat transfer happened.

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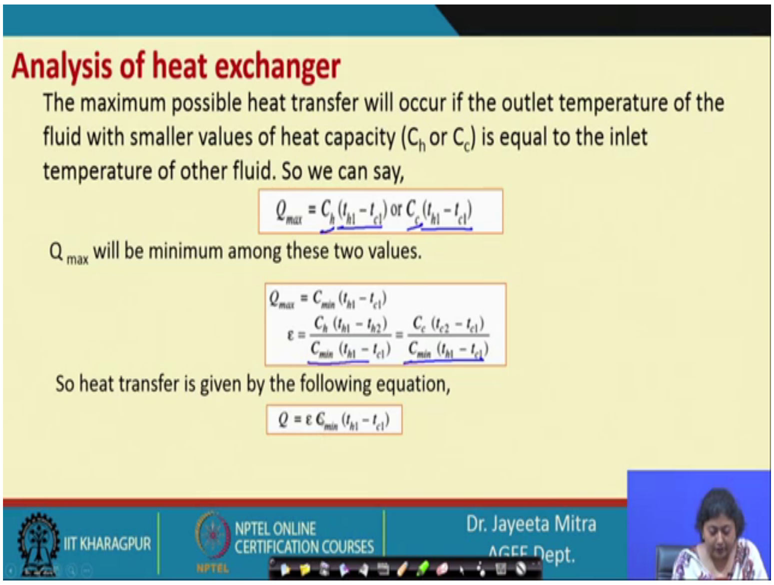

Now, the maximum possible heat transfer will occur if the outlet temperature of the fluid with smaller values of heat capacity that is either C h or C c is equal to the inlet temperature of other fluid. So, it means that heat capacity the term C h or C c right now so C h or C c which is respectively the heat capacity of hot fluid and cold fluid. So, this is equal to m h dot into C p h and this is equal to m c dot into C p c right, now if the flow rate of this fluid the hot fluid is less or if the specific heat that is heat required to increase per unit temperature a for that particular fluid is lower so this will be lower and similar is the case of cold fluid right. So, if this is low either C h or C c; that means, the maximum heat transfer t h 1 c h into t h 1 minus t h 2 ok.

So, Q is equal to C h into t h 1 minus t h 2 or t c 2 minus t c 1. So, if this is small or this is small so this difference will be very high and if it happen that is the maximum heat transfer happens; so what will be there the outlet temperature of the fluid for which the heat capacity is minimum the outlet temperature will be inlet temperature of the other fluid ok. So, that is the maximum amount of heat transfer that may takes place right.

So, for example, if the if C C c if the cold fluid heat capacity of the cold fluid is the minimum in this case ok, so outlet temperature of the fluid with smaller values of heat capacity. So, then it is equal to the inlet temperature of other fluid right so in that case if this is minimum this is minimum t c 2 will be equal to t h 1 and if c h is minimum. So, t h 2 will be equal to t c 1.

So, then we can say that Q max will be C h into t h 1 minus t c 1 or C c into t h 1 minus t c 2, this happen because t h 1 minus t h 2 now since, C h is minimum so t h 2 will be transferred by t c 1 outlet will be inlet of the other fluid so, it is t c 1 or C c if it is minimum then t c 2 minus t c 1 so, outlet of cold fluid will be equal to inlet of the other fluid t h 1 right. So, maximum heat transfer will be this one that is a maximum extend of transfer of heat we can achieve. So, Q max will be minimum among these 2 values ok. So, now Q max that is C min whatever it may be either C h 1 or C c both the case; what we are getting that C minimum into t h 1 minus t c 1 t h 1 minus t c 1 here also t h 1 minus t c 1 only thing either C h is minimum or C c is minimum right.

So, we can write Q max equal to C min t h 1 minus t c 1 so, effectiveness will be the actual transfer in case of hot fluid that we are getting that is C h into t h 1 minus t h 2 by C minimum. So, if C h is C h becomes minimum in that case outlet will be t h 2 will change by t c 1 so we can write C minimum into t h 1 minus t c 1 ok. Similarly, if we consider cold fluid for finding the effectiveness we can write actual heat transfer that is C c t c 2 minus t c 1 divided by C minimum t h 1 minus t c 1. So, in this case C h is minimum and in this case C c is minimum ok. So, this will be effectiveness.

So, heat transfer is given by the following equation that is Q is equal to effectiveness so Q will be equal to effectiveness into C minimum into t h 1 minus t c 1 because, actual heat transfer, actual heat transfer is this one or this one ok. So, this is equal to Q actual heat transfer either this or this, now actual heat transfer will be in effectiveness into this value C minimum into t h 1 minus t c 1.

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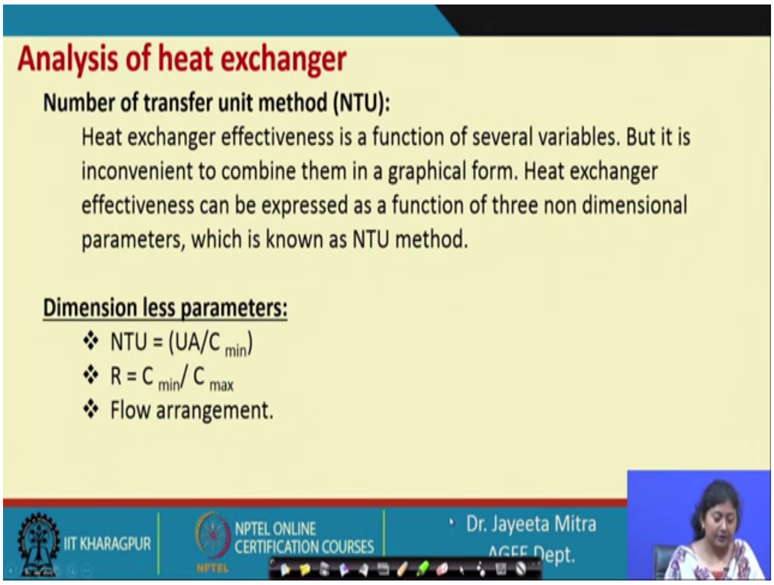

Now, what is number of transfer unit method ok, NTU method it is very common in case of calculating the heat exchanger effectiveness in terms of NTU we generally calculate and it just given in the specification of heat exchanger as well. So, heat exchanger effectiveness is a function of several variables, but it is inconvenient to combine them in a graphical form.

Heat exchanger effectiveness can be expressed as a function of three non dimensional parameter, which is known as NTU method so, what are those parameters, first is NTU the value is U A by C minimum U is the overall heat transfer coefficient watt per meter square degree Celsius or meter square degree Kelvin, A is the area meter square by C minimum that is m dot mass flow rate into specific heat. So, this is one parameter the other is R capacity ratio C minimum by C max and then the other factor that we need to consider is flow arrangement.

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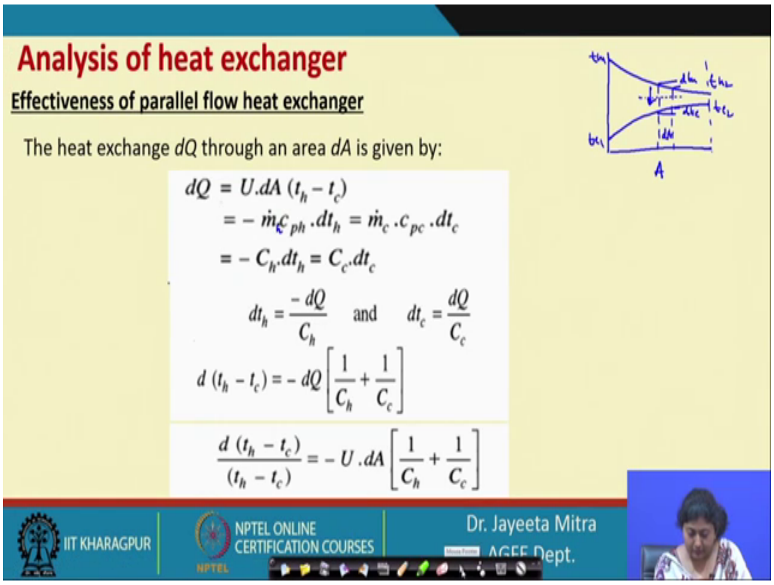

So, first we will see the effectiveness of parallel flow heat exchanger so for parallel flow heat exchanger in the in the previous class we have derived this for the log mean temperature difference that: how we can relate the differential change in the temperature for a differential area and then we have equated the change for hot and cold fluid to find the log mean temperature difference. So, here also we will do the same thing so just to have the idea of the heat transfer I am drawing the profile temperature profile. So, this is the hot fluid and this is the cold fluid and I am taking a small area d A. So, this is t h 1 t c 1 t h 2 t c 2 and this one is d t h d t c right. So, heat is coming from the hot fluid to the cold fluid.

The heat exchange d Q through the area d A so; heat exchange that will be U into d A into t h minus t c. So, U is the overall heat transfer coefficient as I mentioned that there will be a surface, there will be a surface through which these two fluids are exchanging heat because always heat exchange happens through happens through a surface in case of heat exchanger. So, overall heat transfer coefficient U based on the conductivity of the surface and both the side hot fluid and cold fluid side convective heat transfer coefficient or fouling whatever may be there we will calculate U we have already discussed how overall convective heat transfer coefficient can be determined right.

So, U into d A that is the elemental area into temperature difference between the hot and cold fluid so this difference is the driving force for moving d Q amount of heat through the d A amount of area from the hot fluid to the cold fluid. So, for the hot fluid we can write; m h dot into C p h specific heat into d t h the temperature drop in the hot fluid and we are putting minus sign, because it is reducing with increasing A that is equal to m c dot cold fluid flow rate into C p c into d t c so this is increasing towards increasing A.

So, minus C h into d t h that is equal to C c into d t c this is equal to d Q. So, now, we know that we have already seen that we need to find d t h minus d t c. So, we can write that d Q by this C h and here d Q by C c so what we will do now see d t h equal to minus d Q by C h and d t c is d Q by C c. So, d of t h minus t c, that is the temperature difference between the small area d A that is equal to minus d Q 1 by C h plus 1 by C c. So, C h and C c heat capacity of the hot and cold fluid respectively.

So, then again this d Q that we can write in this form that is U into d A into here t h minus t c was there I have taken this t h minus t c to the left side so d of t h minus t c by t h minus t c. So, the similar form like d theta by theta that we have got in the previous class so, l n theta that will be the term and then we can if we integrate this and here also d A will be; integrated and the value of A will come so finally, the equation that we will get ok.

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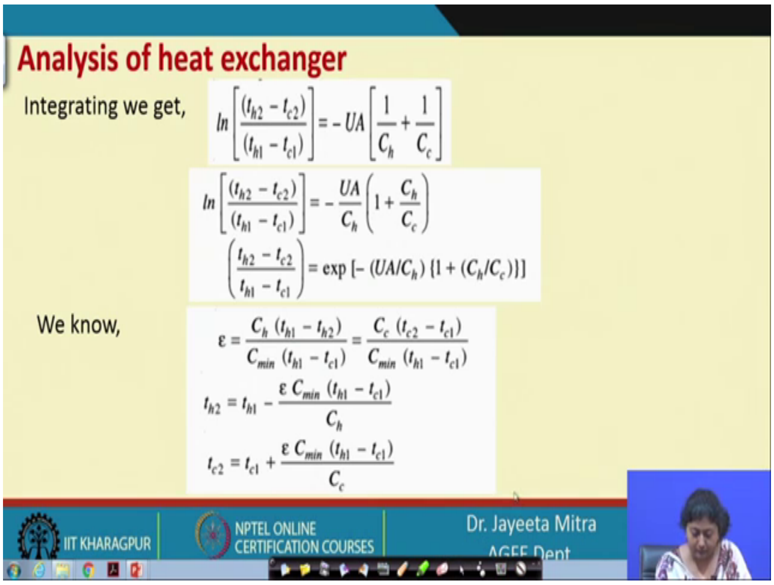

So after integration we are getting this equation, we are integrating from 1-2 so l n of t h 2 minus t c 2 t h 2 minus t c 2 divided by t h 1 minus t c 1 and that is equal to minus U A 1 by C h plus 1by C c. So, then here what we can do is minus U A by C h we can take 1 by C h common so this will be 1 1 plus C h by C c and this term left hand side we can write t h 2 minus t c 2 divided by t h 1 minus t c 1 that is equal to e to the power minus U

A by C h into 1 plus C h by C c ok. So, then what we can do is; we will related with effectiveness, effectiveness what was actual heat transfer divided by the maximum possible heat transfer. So, effectiveness for the hot fluid was C h into t h 1 minus t h 2 by C minimum t h 1 minus t c 1 and for the cold fluid it was C c t c 2 minus t c 1 divided by C minimum t h 1 minus t c 1 ok. So, from this equation and from this equation we need to calculate t h 2 and t c 2 ok.

So, considering this one we can write that effectiveness into C minimum t h 1 minus t c 1, we can write effectiveness into C minimum t h 1 minus t c 1 this is equal to C h into t h 1 minus t h 2 right. So, I can take C h this side right and we can also write that t h 2 t h 2 this is equal to t h 1 minus epsilon C minimum t h 1 minus t c 1 divided by C h ok. Similarly, if I consider this part I can write effectiveness into C minimum into t h 1 minus t c 1 this is equal to C c t c 2 minus t c 1 and here again I will take this C c this side so, then my t c 2 t c 2 will be t c 1 plus effectiveness into C minimum into t h 1 minus t c 1 by C c ok.

So, very clearly you can understand that see t h 2 will be the lower temperature than t h 1 so, t h 1 minus effectiveness into this value, similarly t c 2 will be higher than t c 1 because, t c 1 is going to increase to t h t c 2 so, t c 1 plus effectiveness into C minimum t h t h 1 minus t c 1 by this. So basically, this is kind of a; you know kind of the fraction that we are achieving by the ration of C minimum by C c so, if it is very close to this so, we can get effectiveness higher right.

So, because if effectiveness will be 1 in that case C minimum will be equal to C c and this t c 2 will be eventually t c t h 1 so this is how we have found out t h 2 and t c 2. Now, in the previous in this case that we are we are getting t h 2 minus t c 2 here we will substitute these two equation ok. So, from here t h 2 minus t c 2 we will put this two equation to remove this value t h t2 and t c 2 right.

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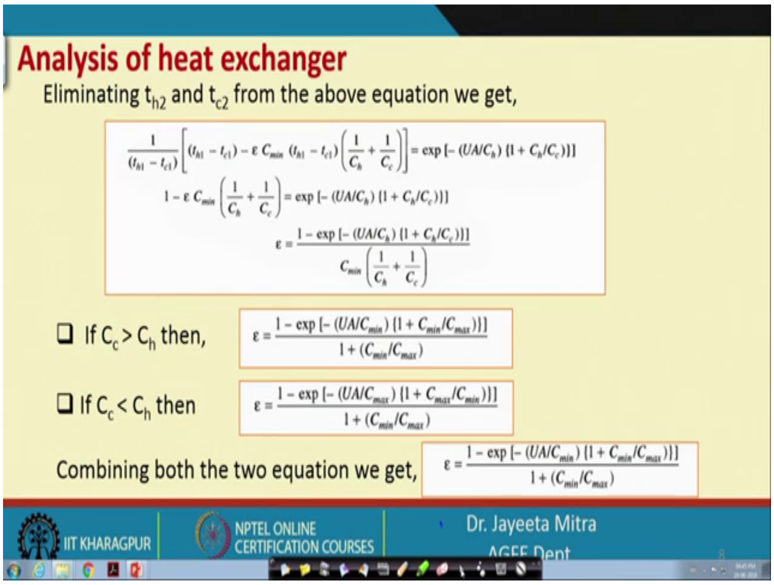

So, eliminating t h 2 and t c 2 from that equation what we are getting that we have put the values of t h 2 and t c 2 in terms of the other parameter that just we have derived so 1 by t h 1 minus t c 1 that is equal to t h 1 minus t c 1 minus effectiveness into C min t h 1 minus t c 1 into 1 by C h plus 1 by C c this will be; the right side is same exponential minus U A by C h into 1 plus C h by C c.

Now, from this we can calculate if if we can take t h 1 minus t c 1 common so this will be cancelled so, 1 minus so we are we are taking this factor t h 1 minus t c 1 from here and here so this will be cancel so 1 minus effectiveness into C minimum ok, 1 by C h plus 1 by C c this is equal to exponential of this term right. So, effectiveness can be termed as 1 minus exponential minus U A by C h into 1 by C h by C c divided by C minimum into 1 by C h plus 1 by C c.

Now the thing is which one is minimal C h or C c based on that we can define effectiveness, first case if C c is greater than C h; that means, C h is our C minimum in that case here, see what will happen that 1 minus U A by C h. So, C h is C minimum now in into 1 plus C h that is C minimum by C max divided by C minimum into C h is minimum here.

So, we take this minimum out so or we take this C min inside so we will getting 1 plus C minimum by C c that is C max. And the 2nd case would be if C c is less than C h that is if C c is the minimum, then the value will be 1 minus exponential minus U A by C max into 1 plus C max by C min, because C h by C c so C h is high now and C c is the minimum divided by 1 plus C minimum by C max ok, because C c is less than C h so C c is the minimum one. So, now we can write here this is minimum so we are getting 1 plus C min by C max here. So, combining both the equation we can get effectiveness is equal to 1 minus exponential minus U A by C min into 1 plus C min by C max divided by 1 plus C min by C max so this is the common equation that we are getting.

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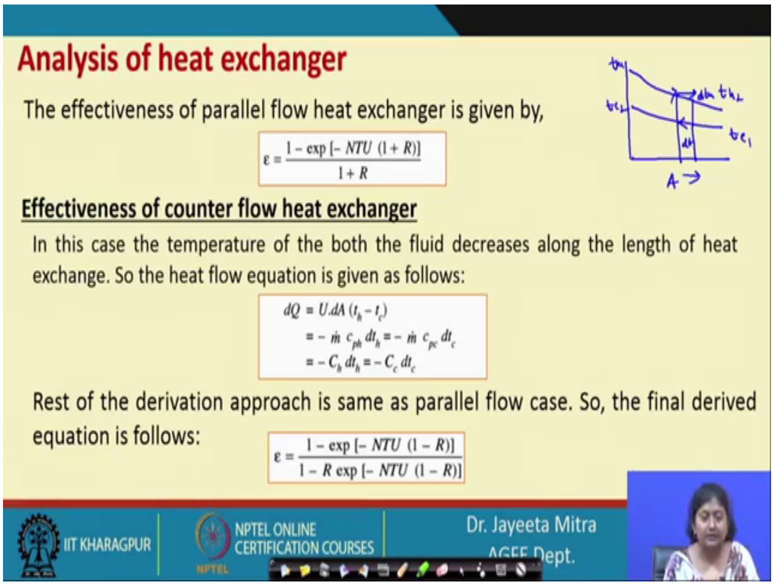

So, the effectiveness of parallel flow heat exchanger is given by 1 minus exponential minus U A by C min that is replaced by NTU number of transfer unit into 1 plus C min by C max that is the capacity ratio R divided by 1 plus R. So, effectiveness for counter flow heat exchanger; this will be done in a similar fashion so, the temperature of both the fluid decreases along the length of heat exchange so the heat flow equation is given as follows: here because the framework will be the configuration of system is such that temperature profile if we draw it will be kind of this so this is t h 1 this is t h 2 and this is t c 1 t c 2 so across the small area d A.

So, if we look towards the small area change we are getting d t h that is negative and also if we move to this direction so temperature a temperature profile of the cold is also decreasing right. So, we can write here as d Q is equal to U d A t h minus t c minus m dot C p h d t h so similar fashion as we did for the earlier case so minus C h into d t h that is equal to minus C c into d t c.

So, rest of the derivation approach is similar as we did for the parallel flow, similarly we will just have d t h minus d t c in terms of d Q C h and C c ok. So, the expression will come as effectiveness equal to 1 minus e to the power minus NTU into 1 minus R divided by 1 minus R that is again capacity ratios C minimum by C max into exponential minus NTU into 1 minus R ok.

So, we will stop here we will continue in the next class.

Thank you.