Thermal Operations In Food Process Engineering: Theory And Applications
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Lecture - 51
Heat Exchangers (Contd.)

So, good morning. We had been doing overall heat transfer coefficient and also we did falling heat transfer right. Now we would like to show for different geometries this is in lecture class number 51 right Heat Exchanger continuation. So, in that for different geometries, let us look at like here.

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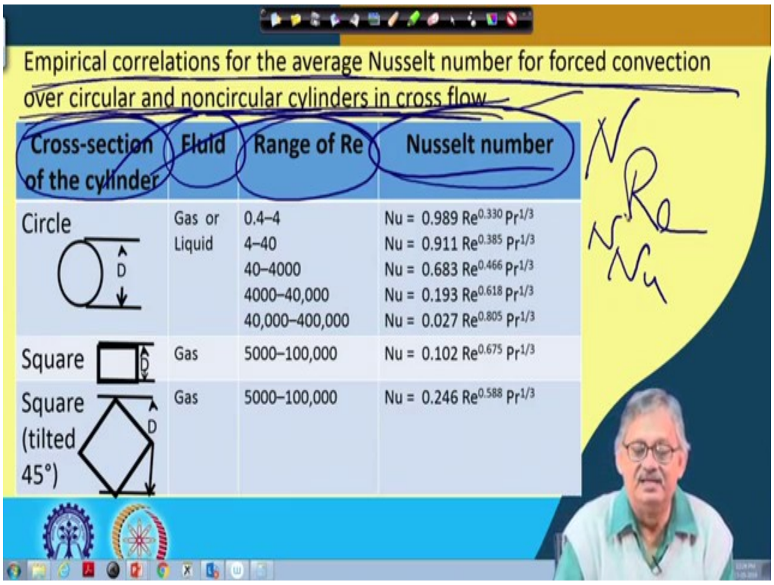

So, there empirical relations, empirical correlations for average Nusselt number for forced convection over circular and noncircular cylinders in cross flow right. Mind it that empirical correlations for average Nusselt number for forced convection over circular and noncircular cylinders in cross flow right.

So, here we have drawn that cross section of the cylinder this is fluid used, this is the range of the Reynolds number as we said earlier also, Re is denoted Reynolds number, in many cases it is also denoted as N_{Re} whatever be and this is the Nusselt number, normally it is designated as a Nu but in many cases it can also be used as N_{Nu} right, whatever be.

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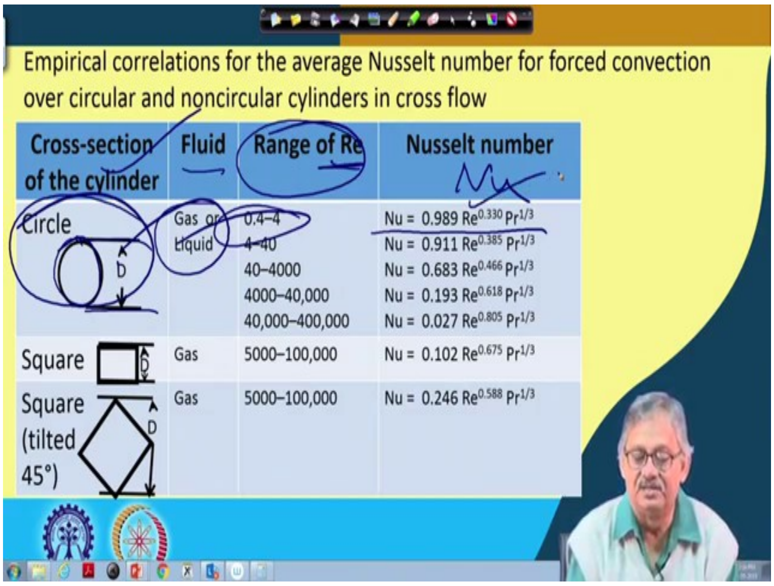

So, this is a Nu this is Re which we have already written right, fluid and sectional area of the cylinder if it is circular if it is a circle like this right. So, which has a diameter like this right and the fluid is gas or liquid the range of Reynolds number if it is between 0.4 to 4, then the relation is Nusselt number = 0.989 $Re^{0.33}$ $Pr^{1/3}$ again it is 0.33 1/3 means 0.33 right.

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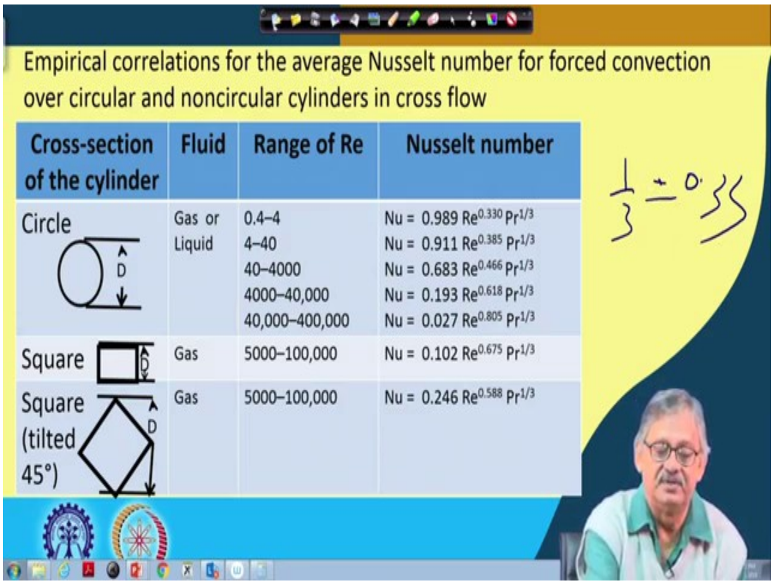

So, $Re^{0.33}$ $Pr^{0.33}$ if it is between 4 to 40 it was 0.4 to 4 between 4 to. So, that is a function of Reynolds number because Re = vDρ / μ right.

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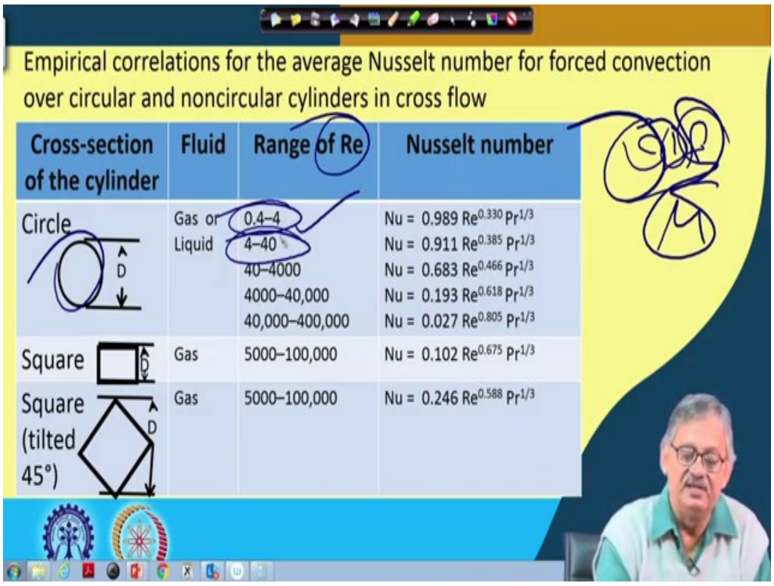

So, you keeping all other factors same for circular. So, D remains same. So, what could vary for the fluid ρ and μ that is same. So, only v can vary so if v is varying Re is also changing that is how it is getting change right. For 4 to 40 Nusselt number is 0.911 $Re^{0.385}$ $Pr^{1/3}$. Within 40 to 4000 Reynolds number it is Nu = 0.683 $Re^{0.466}$ $Pr^{0.33}$.

If it is 40000 to 400000 then it is Nu = 0.027, oh 40 to 4000 we have done. So, 4000 to 40000 it is 0.193 $Re^{0.618}$ and $Pr^{1/3}$ and between 40000 to 400000 it is 0.027 $Re^{0.805}$ $Pr^{1/3}$ for circular cross sectionals of the cylinder, cross section of the cylinder with the diameter D if it is a square right.

If the sectional area is a square, where D is the side of the square and the fluid is gas, if Reynolds number varies between 5000 to 100000 then 100000 rather it is the cell number is equals to 0.102 $Re^{0.675}$ $Pr^{1/3}$ if it is a square but tilted right.

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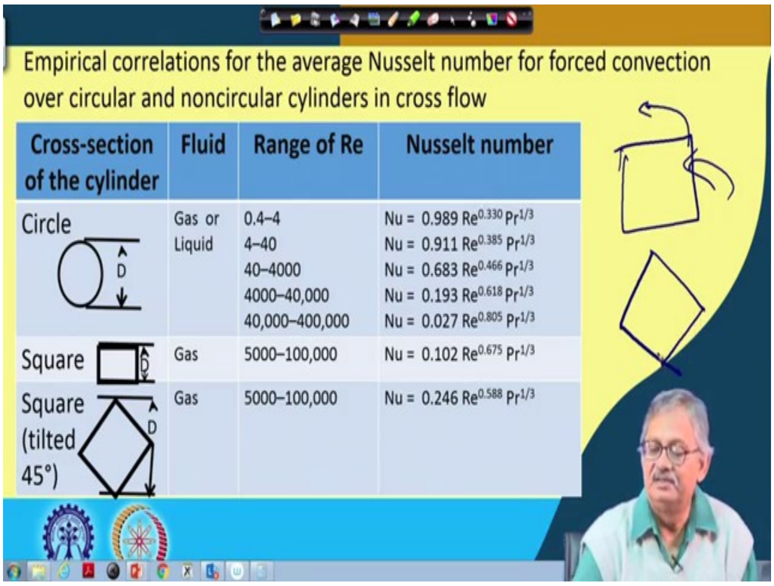

So, a square can be like this right, a square can be like this or if it is tilted means rotated then this can go there. So, that can be like a diamond right. So, that is what it is here. So, a square tilted 45°, again this height is D right that is the here it was side, but here it is the diagonal, diagonal is the D and the gas is the fluid. Again if the Reynolds number between 5000 to 500000 Nusselt number is related as 0.246 $Re^{0.588}$ $Pr^{1/3}$.

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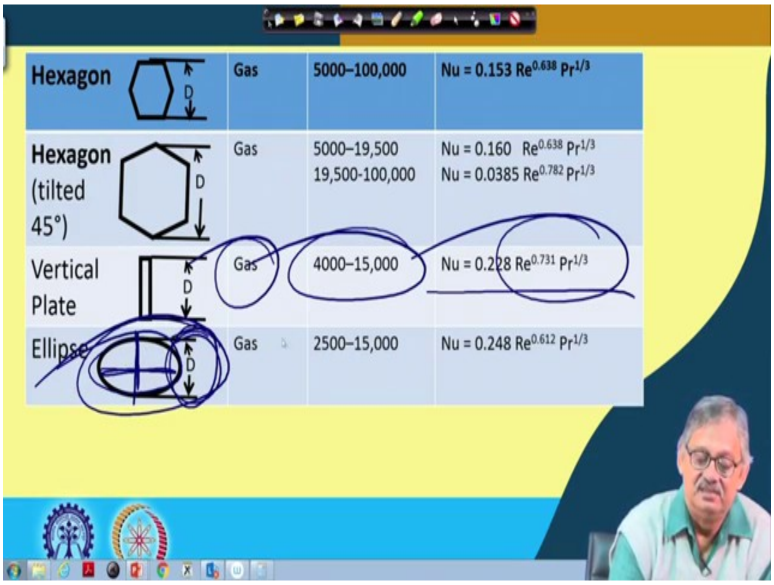

Then for some other geometry we can write, for hexagon if the cross section is hexagonal where the D is like this from one end to the other end right or like this because if it is hexagon all the this side distance should be same. Then if gas is the medium and again 5000 to 100000 is the Reynolds number range then Prandtl Nu = 0.153 $Re^{0.638}$ $Pr^{1/3}$.

If it is hexagon tilted around 45°. So, this has become this right. So, a little tilted. So, then from this, this and this the D is that right. So, D is this so gas if it is again the fluid. So, between 5000 to 19500 Nu = 0.160 $Re^{0.638}$ $Pr^{1/3}$. So, generally this constant is varying right and if it is 19500 to 100000 then Nu = 0.0385 $Re^{0.782}$ $Pr^{1/3}$ and if it is vertical plate like this is a plate, if it is a vertical plate then that vertical distance is this D right.

Then this is the gas which is the medium, between 4000 to 15000 Nu = 0.228 $Re^{0.731}$ $Pr^{1/3}$, if it is elliptical or ellipse right like this, if it is ellipse then this is the major axis this is the minor axis.

So, minor axis is D, then if it is a again gas as the medium between 2500 to 15000 Nu = 0.248 $Re^{0.612}$ $Pr^{1/3}$. So, these are some of the cases which are associated with different configuration of the geometry right.

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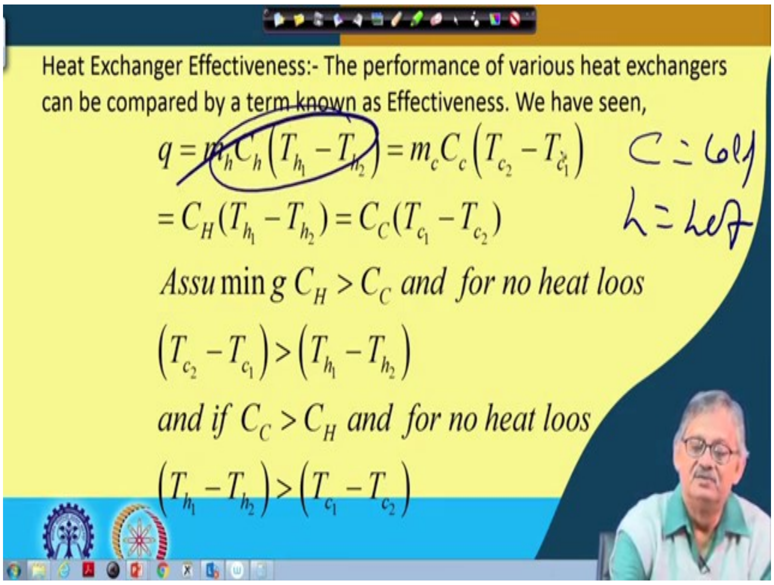

Now, we come to a very important last part of the heat exchangers that is the heat exchanger effectiveness right. We have a heat exchanger that may be very good or very effective with a situation or that may be very non effective with that situation. Who will dictate? Right, who will dictate, how we will judge it?

So, to judge that let us look into that heat exchanger effectiveness right, the performance of various heat exchangers can be compared by a term known as effectiveness. So, we have earlier seen that $q = m_h C_h (T_{h1} - T_{h2})$ that is for the hot fluid and is equals to $m_c C_c (T_{c2} - T_{c1})$ that was for the cold fluid right C for cold, and h for hot right.

So, for the hot fluid m C_v dT for the cold fluid m C_p dT right. So, that here we are not saying C be C_h dull heat capacity. So, it is $C_H (T_h - T_{h2}) = C_C (T_{c1} - T_{c2})$, assuming if we assume C_H is much > or $C_H > C_C$, that is hot fluid heat capacity is greater than cold fluid heat capacity and for no heat loss that is also another very important assumption that there is no heat loss otherwise right. In that case $(T_{c2} - T_{c1}) > (T_{h1} - T_{h2})$ because this product has to be equals to this product right and if $C_H > C_C$ so value of this is more.

So, this has to be less and this has to be more then only it is possible right, to be equated. So, that is why $(T_{c2} - T_{c1}) = (T_{h1} - T_{h2})$ right.

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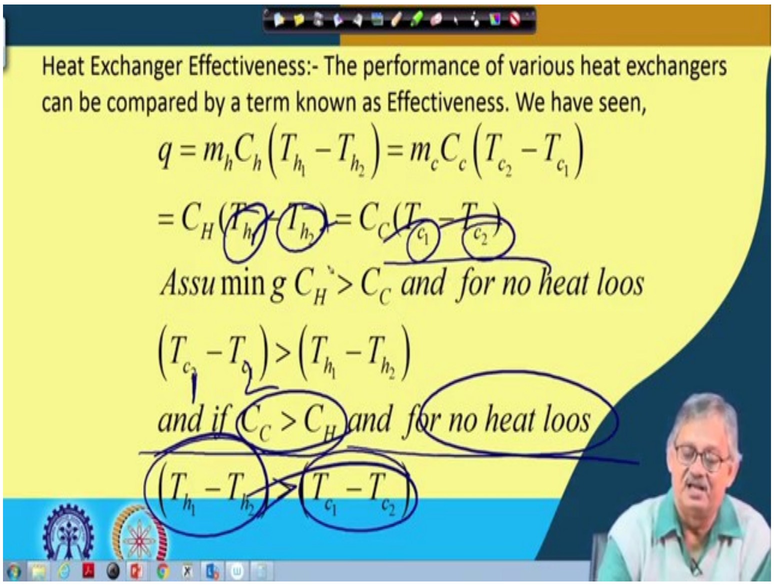

Or this can be written as if $C_C > C_H$ and for no heat loss again $(T_{h1} - T_{h2}) > (T_{c1} - T_{c2})$. So, it can be again $(T_{c1} - T_{c2})$ right.

So, that is what we are writing, that is what is in practice if $h_1 - h_2$, h_1 is higher h_2 is lower, then c_1 has to be lower and c_2 has to be higher. So, to have then it should be $c_2 - c_1$; however, to have this we are saying say mod of this the difference. So, here also that mod of this the difference right. So, that is that case $(T_{h1} - T_{h2})$ must be > $(T_{c1} - T_{c2})$. when $C_C > C_H$ right.

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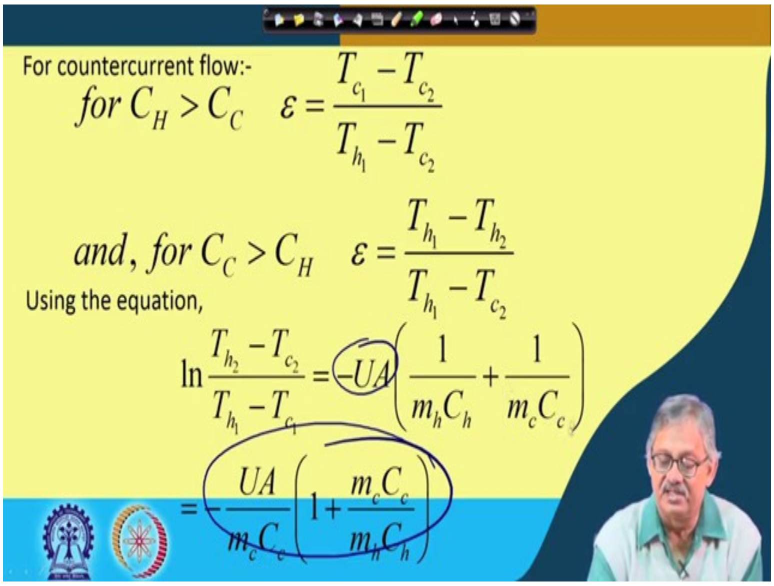

If that be true then let us look at for counter flow we can write, for counter flow you can write for $C_H > C_C$ ε or the effectiveness = $(T_{c1} - T_{c2}) / (T_{h1} - T_{c2})$ and for $C_C > C_H$, if the cold fluids heat capacity is greater than hot fluid heat capacity then $\varepsilon = (T_{h1} - T_{h2}) / (T_{h1} - T_{c2})$ right.

Now, using that equation $\ln ((T_{h1} - T_{c2}) / (T_{h1} - T_{c1}))$ which you have used earlier = $- UA ((1/m_hC_h) + (1/m_cC_c))$, if we use that which can be written as $- UA / m_cC_c$ if we divide both side with the m_cC_c minus of UA, this can be written as $- UA / m_cC_c$ times 1 by because this has become 1. So, $1 + (m_cC_c / m_hC_h)$ right. So, this we you can write that $\ln ((T_{h2} - Tc_2) / (T_{h1} - T_{c1}))$ if $C_C > C_H$ is this right $–UA / m_cC_c (1+ m_cC_c / m_hC_h)$ right.

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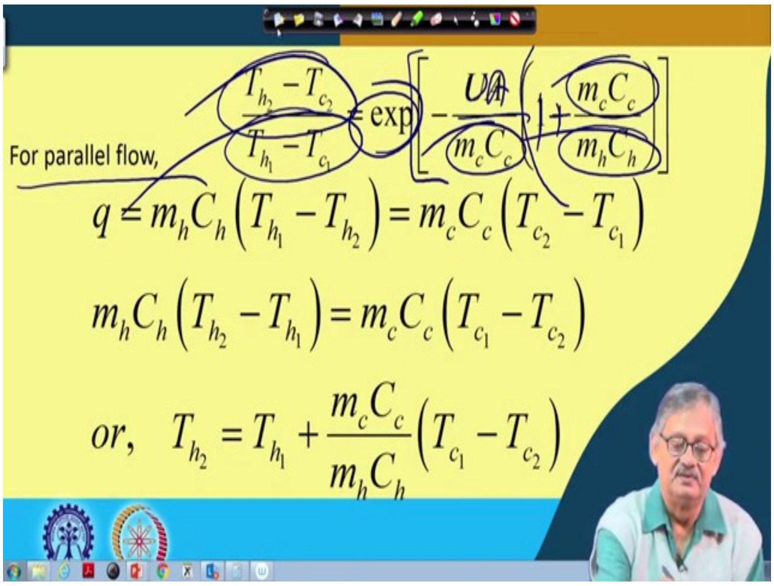

Then we can also write for parallel flow, we can also write for parallel flow $(T_{h2} - Tc_2) / (T_{h1} – Tc_1) = \exp[- UA/m_cC_c (1 + m_cC_c / m_hC_h)$ right. This we can write, this we can write that $q = m_hC_h (T_{h1} – T_{h2}) = m_cC_c (T_{c2} – T_{c1})$ right. Or $m_hC_h (T_{h2} - T_{h1})$ is $m_cC_c (T_{c1} – T_{c2})$ right, this we can write or $T_{h2} = T_{h1} + ((m_cC_c / m_hC_h) (T_{c1} -T_{c2}))$.

So, we have again made it m_cC_c / m_hC_h right. So, this if we write we can then T_h we have written in this form. So, we are we were in this that C_C if $C_C > C_H$ right then $(T_{h1} - T_{h2}) > (T_{c1} – T_{c2})$. Why it is so that we have said earlier, I am not repeating.

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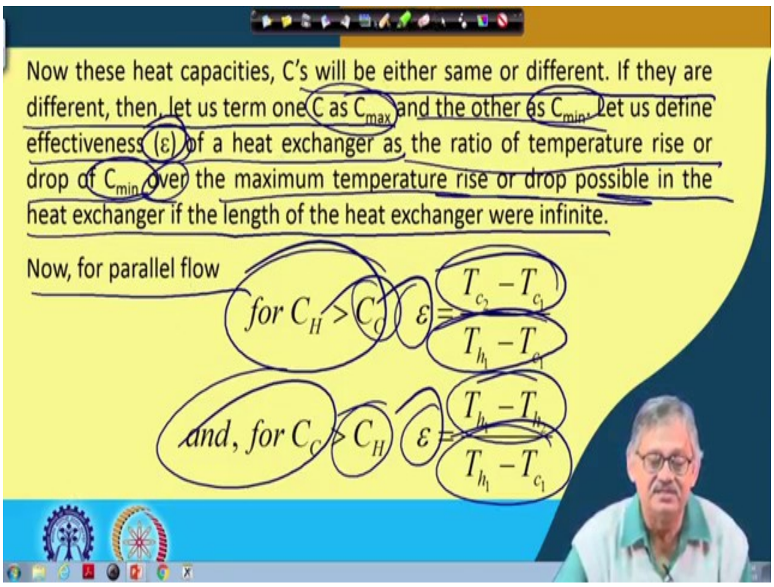

Now, that we can say these heat capacities or C's will be either same or different if they are different then let us turn one of them as C_{max}, one of them as C_{max} and the other as C_{min}; right.

So, let us define effectiveness epsilon of a heat exchanger as the ratio of temperature rise or drop of C min over the maximum temperature rise or drop possible in the heat exchanger, if the length of the heat exchanger were infinite right. Now, for parallel flow C_H; if $C_H > C_C$ then $\varepsilon = (T_{c2} - T_{c1}) / (T_{h1} - Tc_1)$ and for $C_C > C_h$ $\varepsilon = (T_{h1} - T_{h2}) / (T_{h1} - Tc_1)$ right.

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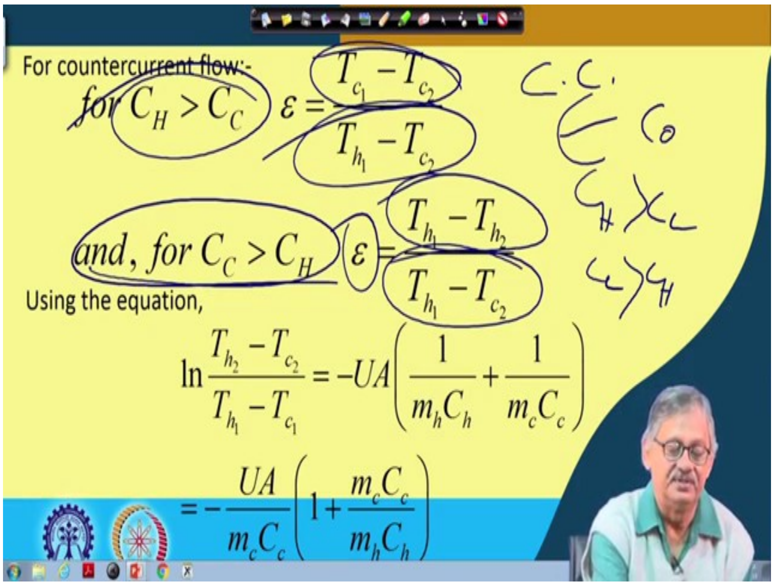

Then for counter flow this epsilon is like that, for $C_H > C_C$ $\varepsilon = (T_{c1} - T_{c2}) / (T_{h1} - Tc_2)$ and for $C_C > C_H$ $\varepsilon = (T_{h1} - T_{h2}) / (T_{h1} - Tc_2)$. So, all the epsilons whether $C_H > C_C$ or $C_C > C_H$ depending on the situations and for counter current for co current we have defined all epsilon values right.

Now, using them we have already use this equation, that ln = - UA of this equals to - UA / m_cC_c ; m_cC_c (1 + m_cC_c / m_hC_h) right this we have done earlier also before the break.

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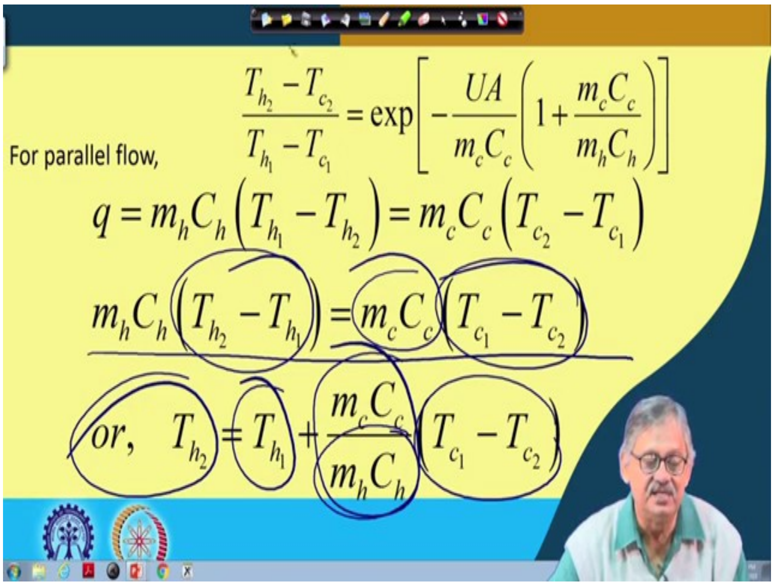

Now, for parallel flow this where we got stuck that $(T_{h2} - T_{c2}) / (T_{h1} - T_{c1})$ = exp [-UA/ m_cC_c (1 + m_cC_c / m_hC_h) right and q = m_hC_h (T_{h1} – T_{h2}) = m_cC_c (T_{c2} - T_{c1}) right and m_hC_h (T_{h2} - T_{h1}) = m_cC_c (T_{c1} - T_{c2}). So, T_{h2} = T_{h1} + m_cC_c; m_cC_c / m_hC_h (T_{c1} - T_{c2}) that is T_{h2} right.

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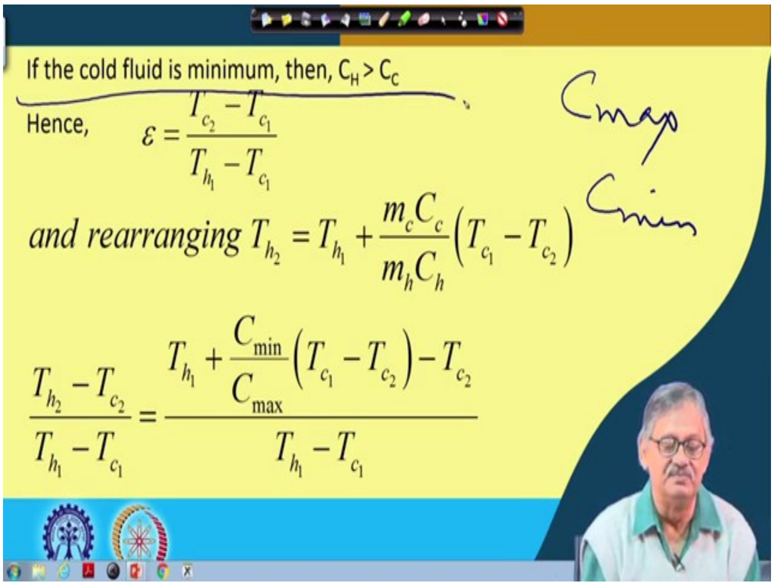

So, if the cold fluid is minimum. So, we said one will be max, C_{max} and another will be C_{min} and now we are assuming if the cold fluid is minimum right then $C_H > C_C$, then only C_C can be minimum then ε = (T_{c2} - T_{c1}) / (T_{h1} - T_{c1}) and this are rearrangement we can write $T_{h2} = (T_{h1} + m_cC_c / m_hC_h)(T_{c1} - T_{c2})$ right. So, we can rewrite that is $(T_{h2} - T_{c2}) / (T_{h1} - T_{c1}) = (T_{h1} + C_{min}/C_{max}(T_{c1} - T_{c2}) - T_{c2}) / (T_{h1} - T_{c1})$ right.

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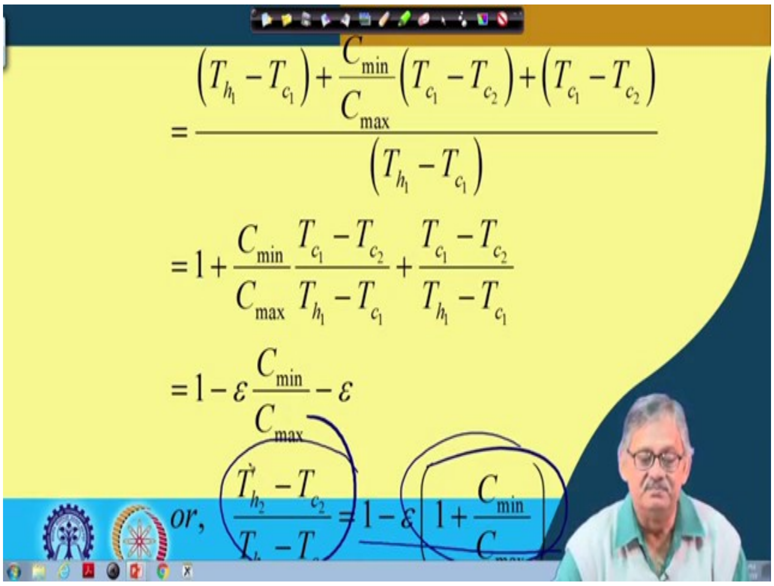

So, this we can also say that, this can also be written that this is equals to $(T_{h1} - T_{c1}) + C_{min}/C_{max}(T_{c1} - T_{c2}) + (T_{c1} - T_{c2}) / (T_{h1} - T_{c1})$. So, this can be written as $1 + C_{min}/C_{max}(T_{c1} - T_{c2}) / (T_{h1} - T_{c1}) + (T_{c1} - T_{c2}) / (T_{h1} - T_{c1})$ right. So, this can also be rewritten as $1 - \varepsilon C_{min} / C_{max} - \varepsilon$ or this can be rewritten as $(T_{h2} - T_{c2}) / (T_{h1} - T_{c1}) = 1 - \varepsilon(1 + C_{min} / C_{max})$ right.

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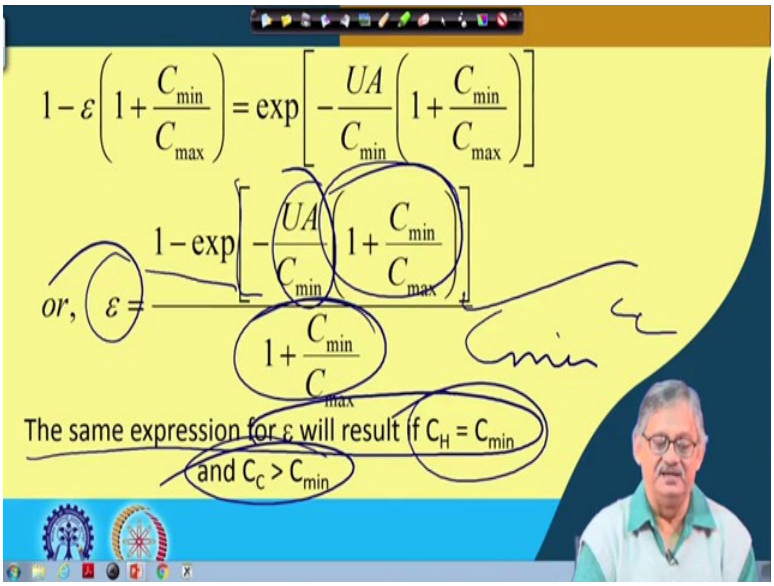

So, this we can rewrite as 1 - ε; (1 - ε) (1+ C_{min} / C_{max}) = exp[- UA / C_{min} (1 + C_{min} / C_{max}) right or ε = 1 - exp[- UA / C_{min} (1 + C_{min} / C_{max}) / 1+ C_{min} / C_{max} right. So, this is for where C_{min} is the C_C right.

So, the same expression epsilon will result if C_H is C_{min} and C_C > C_{min} right, the same expression can be obtained. So, this is how we can find out for epsilon that is the heat exchangers effectiveness can be found out depending on the minimum capacity or maximum capacity of the exchanger, whether it is hot fluid or whether it is a cold fluid that does not matter but the expression will become same and we can express that in terms of C_{min} or C_{max} as the effectiveness right.

So, now, our time is over. So, next class we will continue and complete it in terms of net transfer unit NTU right ok.

Thank you.