Thermal Operations In Food Process Engineering: Theory And Applications
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Lecture - 52
Heat Exchangers (Contd.)

So, good morning, we have been doing epsilon that is effectiveness of the Heat Exchanger and perhaps we have completed up to the parallel flow. What is the expression for effectiveness whether C_{min} or C_{max} is hot fluid or cold fluid depending on that, we had developed the expressions. Now we will do the same for counter flow. So, it is the lecture number 52 on Heat Exchangers, this is continued.

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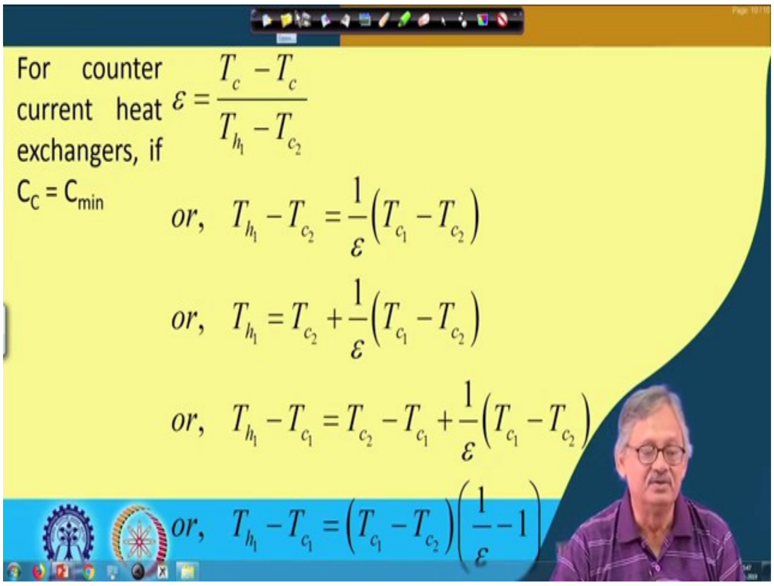

And if we look at for parallel flow I support counter flow, counter current flow then we can write this $\varepsilon = T_c$; obviously, here missing is that T_{c1} and this is T_{c2}, right.

Because we could come to know from here, because we multiplied these thing with this and this thing we kept intact. So, we get that T_c, oh no we took these thing there and these thing here rather this way, we brought it here and we took it there; so we can come to know that this was T_{c1} and this was T_{c2}, by some mistake we could not make it, right.

So, here it is T_{c1} and here it is T_{c2}. So, $(T_{h1} - T_{c2}) = 1 / \varepsilon \ (T_{c1} - T_{c2})$; or this T_{h1} if you separate, then we get T_{c2} plus this, so $1 / \varepsilon \ (T_{c1} - T_{c2})$. So, again on rearranging we can write $(T_{h1} - T_{c1}) = (T_{c2} - T_{c1})$; because we have added one T_{c1} here, we have also added one T_{c1} here.

So, that is why it is going up. So, plus $1 / \varepsilon$ whichever was here $(T_{c1} - T_{c2})$. So, this can further be rearranged as $(T_{h1} - T_{c1})$ right; this is equals to $(T_{c1} - T_{c2})$, if we take $(T_{c1} - T_{c2})$ common, right. So, $1 / \varepsilon$ comes first minus 1 because here it is $(T_{c1} - T_{c2})$, one negative will come right.

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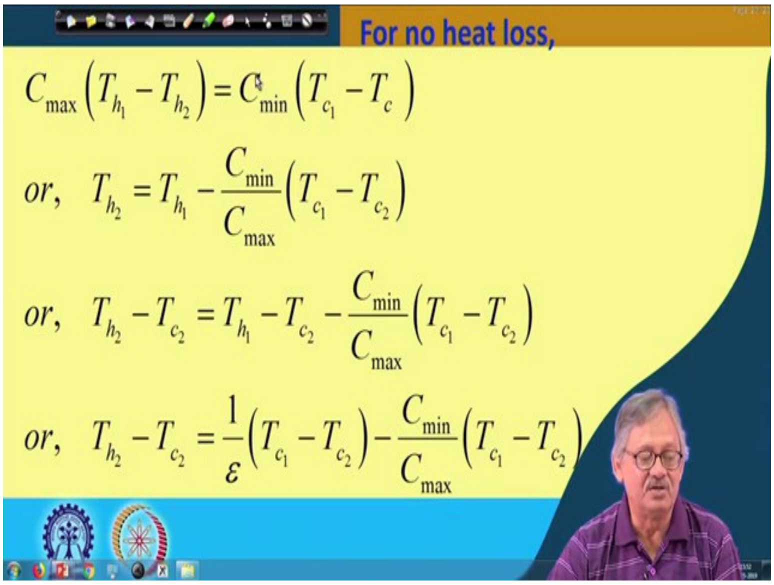

So, if that be true, then we can rewrite that no heat loss why you are saying; that normally any heat exchanger though there is if this is a heat exchanger; obviously, depending on the fluids right and this is in this particularly it is counter flow.

So, depending on that whether it is co or counter whatever it be, there will be some heat loss with the surrounding right. So, that cannot be avoided, but for all practical purposes if we assume that surrounding heat loss is negligible and that is what we are assuming that there is no heat loss, then only we can easily do it; otherwise taking account those heat loss will make it more complicated, right.

So, it can be done, I am not saying it cannot be; but that will make it more complicated the whole system. So, we can write C_{max} $(T_{h1} - T_{h2}) = C_{min}$ $(T_{c1} - T_{c2})$, right. And C_{max} and C_{min} we had said in the previous day, in the previous class rather; then $(T_{h2} - T_{h1})$ is $-C_{min} / C_{max}$ $(T_{c1} - T_{c2})$, because it was $(T_{h1} - T_{h2})$.

Now we have made $T_{h2} = T_{h1}$ minus right; so we have kept this on that side and brought it to this side, so that is why T_{h1} minus. Then $(T_{h2} - T_{c2})$ that can be written as $(T_{h1} - T_{c2})$ - C_{min} / C_{max} because we have added here 1 - T_{c2} we have also added on right side - T_{c2}. So, C_{min} / C_{max} times $(T_{c1} - T_{c2})$.

So, this can be again rewritten $(T_{h2} - T_{c2}) = 1 /\varepsilon$ right; which we have seen earlier $1 /\varepsilon\ (T_{c1} - T_{c2})$, right $-C_{min} / C_{max}$ as usual into $(T_{c1} - T_{c2})$.

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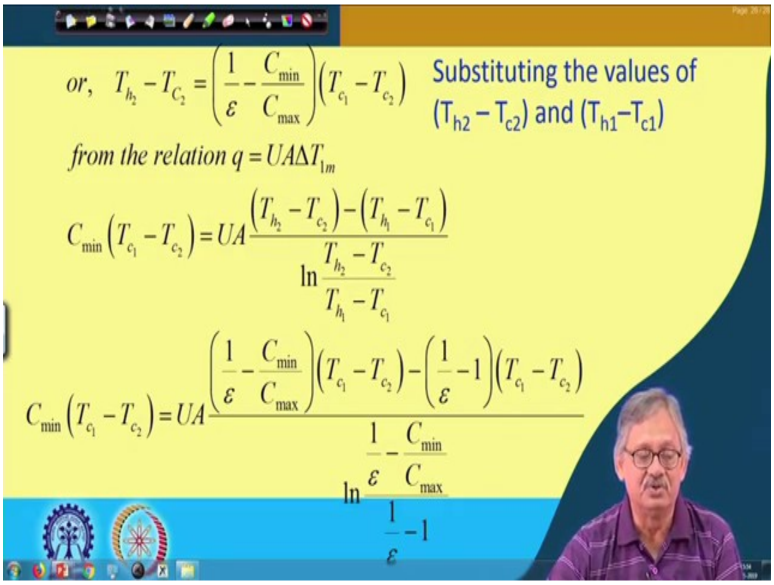

So, this on further simplification, we can write that $(T_{h2} - T_{c2}) = (T_{h2} - T_{c2}) = (1 /\varepsilon - C_{min} / C_{max})\ (T_{c1} - T_{c2})$ right. This is done by subtracting values of $(T_{h2} - T_{c2})$ and $(T_{h1} - T_{c1})$ right. And from the relation, what we know $q = U\ A\ \Delta T_{lm}$; we can write that $C_{min}\ (T_{c1} - T_{c2}) = U\ A\ \Delta T_{lm}$ instead of that we write $(T_{h2} - T_{c2}) - (T_{h1} - T_{c1}) / \ln\ (T_{h2} - T_{c2}) / (T_{h1} - T_{c1})$, right.

So, here all the time mind it that this difference minus this difference should be always on the numerator, this difference and denominator this difference, right. So, then at least this part will not be wrong; but in actual when you are having, then you have to take care that flow direction right and which one is parallel or which one is counter that you have to take care, ok.

So, we write $C_{min}\ (T_{c1} - T_{c2})$ is this; then we can rewrite this as $C_{min}\ (T_{c1} - T_{c2})$ = UA right times, instead of this we write $(1 /\varepsilon - C_{min}/C_{max})\ (T_{c1} - T_{c2}) – (1/\varepsilon - 1)\ (T_{c1} - T_{c2})$ /ln $(1/\varepsilon - C_{min} /C_{max}) / (1/\varepsilon - 1)$.

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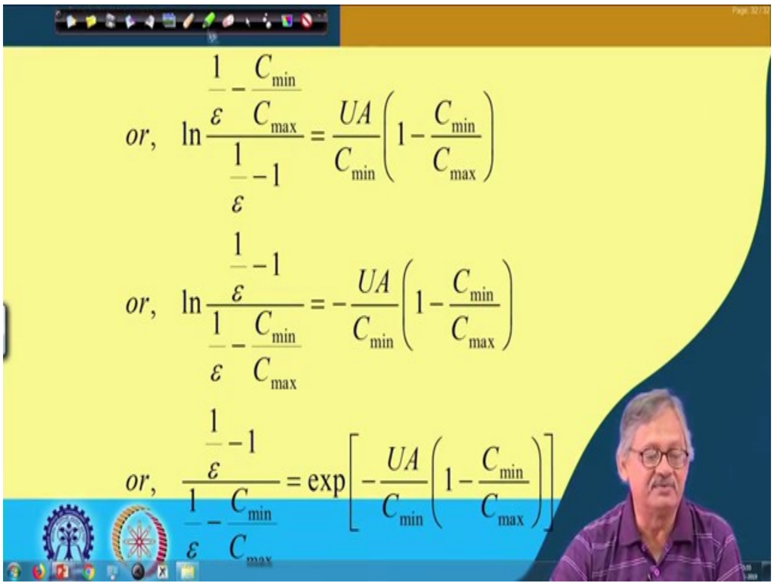

So, this we can further simplify, writing that ln (1/ε - C_{min} / C_{max}) / (1/ε - 1) = U A / C_{min} (1 - C_{min} / C_{max}) right. Or ln of this that (1/ε-1) / (1/ε - C_{min} / C_{max}) this we just inverse is equals to UA / C_{min} that is why we have brought to a negative here, we have inversed it times 1- C_{min} / C_{max} right.

So, this means (1/ε - 1) / (1/ε - C_{min} / C_{max}) is equals to, this we can write exp[- UA/ C_{min} (1 - C_{min} / C_{max}) right.

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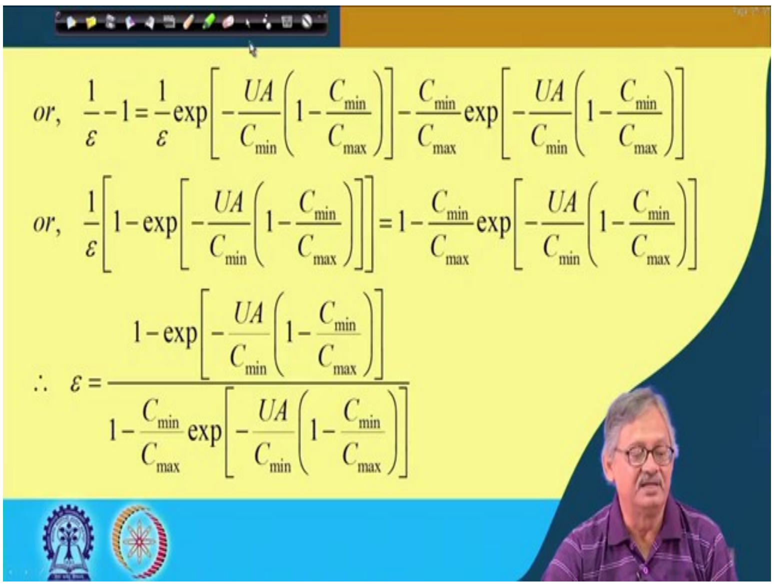

So, this we can further write in this form, that $1/\varepsilon - 1 = 1/\varepsilon \exp[- UA/C_{min} (1 - C_{min}/C_{max})] - C_{min} /C_{max} \exp[- UA/C_{min} (1 - C_{min}/C_{max})]$ right. Or we can rewrite that, $1/\varepsilon (1 - \exp[- UA/ C_{min} (1 - C_{min}/C_{max})]$ right this $= (1 - C_{min}/C_{max}) \exp[- UA/C_{min} (1 - C_{min}/C_{max})]$ right. Or ε we can write in the form $1 - \exp[- UA/C_{min} (1 - C_{min}/C_{max})] / (1 - C_{min}/C_{max}) \exp [- U A / C_{min} (1 - C_{min}/C_{max})$.

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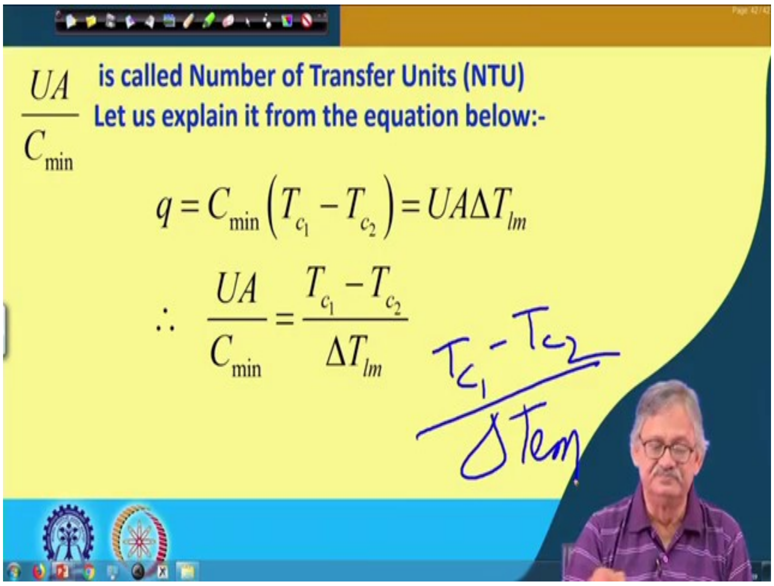

Now, this we can further rewrite this way, that you we define a term that is called UA/ C_{min}; we define a term that is called UA/C_{min}. And this we can term as Number of Transfer Units or NTU Number of Transfer Units NTU, right. If we define UA/C_{min} as NTU and explain it from the equation that here, $q = C_{min} (T_{c1} - T_{c2})$ that we know which is equals to $UA \Delta T_{lm}$, right.

So, we can write $UA/C_{min} = (T_{c1} - T_{c2}) / \Delta T_{lm}$. So, our NTU which we are calling as UA/ C_{min} right, this is nothing but ΔT that is $(T_{c1} - T_{c2})$ right sorry, there is $(T_{c1} - T_{c2})$ right over ΔT_{lm}, right. So, if that be true, then we apply it that UA / C_{min} as NTU.

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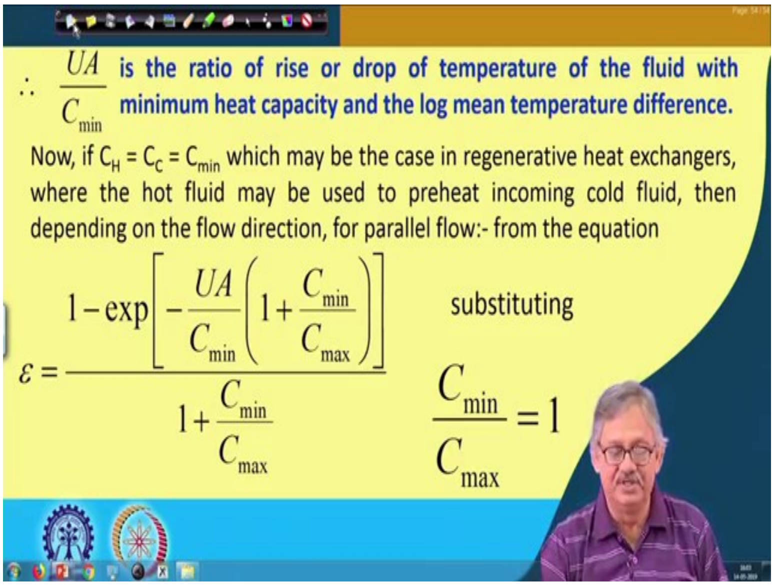

And we can write that UA / C_{min}, UA / C_{min} is the ratio of rise or drop of the fluid, temperature of the fluid with minimum heat capacity and the log mean temperature difference that is what we had shown in the previous slide also. That, in the previous slide this was our thing, that UA / C_{min} sorry, UA / C_{min} was ΔT_c right or (T_{c1} - T_{c2}) right, (T_{c1} - T_{c2}) that is why we are saying rise or drop; because we do not know whether that is (T_{c1} - T_{c2}) is positive or (T_{c1} - T_{c2}) this is negative right. This we do not know. Since we do not know we are saying that rise or drop ratio of the rise or drop of the temperature this is the ratio to the log logarithmic temperature, right.

So, because ΔT_{lm} is nothing, but not a temperature but a ratio right; because that was also ΔT by some ΔT. So, it is dimensionless, right. So, we can say that U A / C_{min} is the ratio of rise or drop of temperature of the fluid with minimum heat capacity and this is the and the log mean temperature difference that is the ratio. Now if $C_H = C_C = C_{min}$, right. So, that is C hot is equals to or heat capacity of hot fluid is equals to heat capacity of cold fluid is the minimum heat capacity.

If that be the case, which may be the case in regenerative heat exchangers; regenerative heat exchanger are those where your extra fluid or extra heat which is not utilized or the unutilized heat can be regenerated or utilized by sprinkling or preheating, whatever be the case right. So, that is called regenerative heat exchanger.

So, if that is used, the hot fluid may be used to preheat incoming cold fluid or the reverse we can say the cold fluid can be reused to preheator to or cold fluid can be use to reduce the temperature of the outcome of the hot fluid; whatever be the case depending on that your regeneration of the heat will be there and then depending on the flow direction for parallel flow from the equation already we had, epsilon is equals to 1 minus exponential minus U A / C_{min} (1 + C_{min} / C_{max}) / (1 + C_{min} / C_{max}), right

So, in that substituting C_{min} / C_{max} = 1, because here we had taken it to be that; then if we substitute that then we get.

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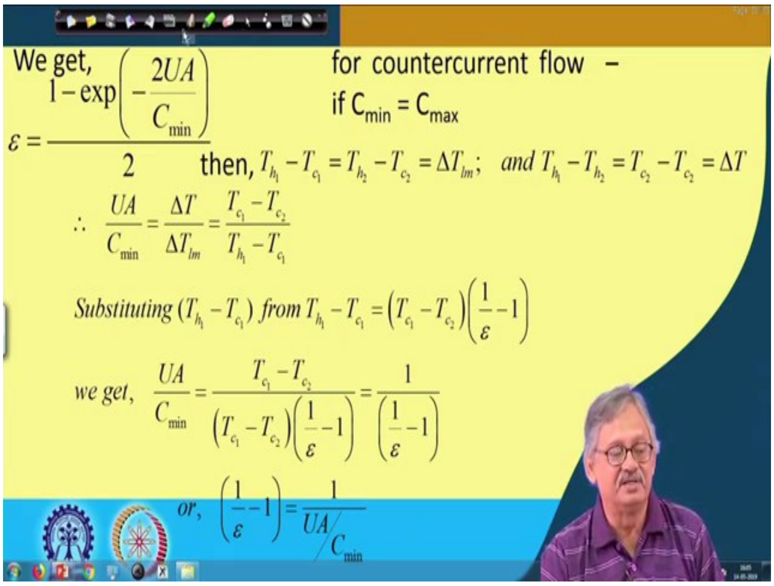

Then we get ε = 1 – exp [-2UA/C_{min} / 2], right. And for counter flow that was for parallel flow C_{min} is, if C_{min} = C_{max}; then (T_{h1} - T_{c1}) = (T_{h2} - T_{c2}) = ΔT_{lm}; and (T_{h1} – T_{h2}) = (T_{c1} - T_{c2}) and of course, this (T_{h1} – T_{h2}) = (T_{c2} - T_{c1}) this is this is (T_{h1} - T_{c1}) is (T_{h2} - T_{c2}) = ΔT_{lm} ok, and (T_{h1} – T_{h2}) = (T_{c2} - T_{c1}) = ΔT_{lm}.

So, if that be the case, then UA/ C_{min} = ΔT / ΔT_{lm} = yeah this is (T_{c1} - T_{c2}) / (T_{h1} - T_{c1}) right, this one right. So, this is (T_{c1} - T_{c2}), so (T_{c1} - T_{c2}) / (T_{h1} - T_{c1}), right. So, we can write that substituting this value of (T_{h1} - T_{c1}) from this (T_{h1} - T_{c1}) = (T_{c1} - T_{c2}) / 1/ε - 1. We can rewrite UA/C_{min} = (T_{c1} - T_{c2})/ (T_{c1} - T_{c2}) (1/ ε -1); that is equals to 1/ ε -1 or 1/ ε -1 = 1/U A /C_{min}.

So, this we can then write in this form.

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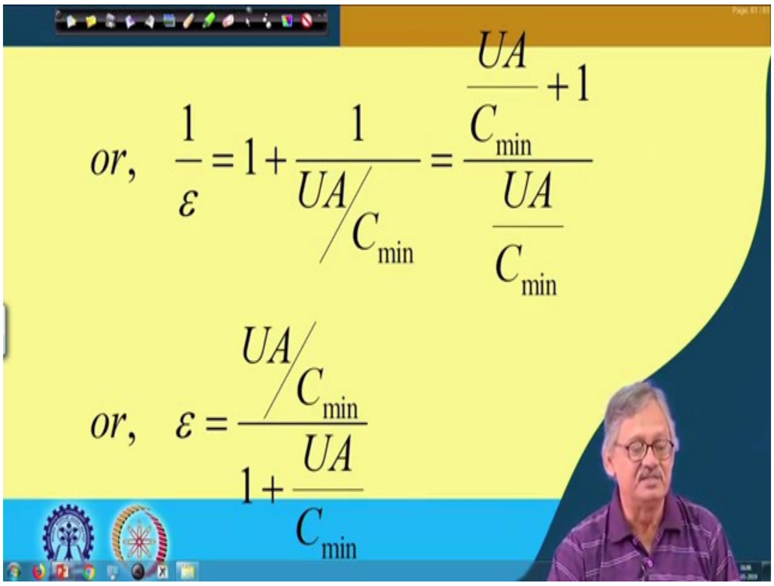

That 1/ ε = 1+ 1 / UA / C_{min} = U A /C_{min} + 1/UA / C_{min}, right. So, ε = U A / C_{min} /1 + U A / C_{min}, this we can write in the form of NTU, right.

So, where UA / C_{min} is was nothing but, that NTU right. So, this is NTU / 1+ NTU right. So, that is what we are expressing in terms of number of transfer units and that is related with the epsilon that is effectiveness right.

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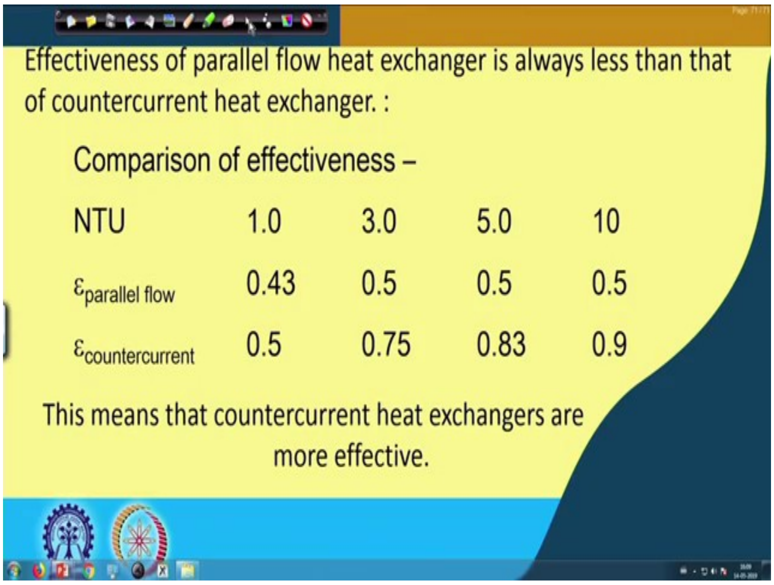

Now if we look at the effectiveness versus NTU, if we look at effectiveness of parallel flow heat exchanger is always less than that of the counter flow heat exchanger. How, you see for comparison we are writing NTU; if it is NTU, NTU you we said U A / C_{min} right, that was the NTU.

So, if that is equals to 1 right, then for parallel flow you that effectiveness ε = 0.43; whereas, for counter flow it is 0.5. So, this is less than, right. So, this is less than this. Similarly if it is for NTU = 3, right; effectiveness for parallel flow is if it is 0.5 then that for counter flow it is 0.75, again parallel flow is less than counter flow, right.

Similarly, if it is 5 NTU = 5, then it is for parallel flow 0.5; then for counter flow it is 0.83. So, all the time counter flow is higher value for effectiveness than that of the parallel flow and if NTU = 10 and then for counter flow effectiveness is 0.5 whereas, for a sorry for parallel flow effectiveness is 0.5; whereas, for counter flow it is 0.9, right.

So, we can say that, this counter flow heat exchanger has always higher effectiveness than that of the parallel flow, right. So, this means that counter current heat exchangers are more effective right.

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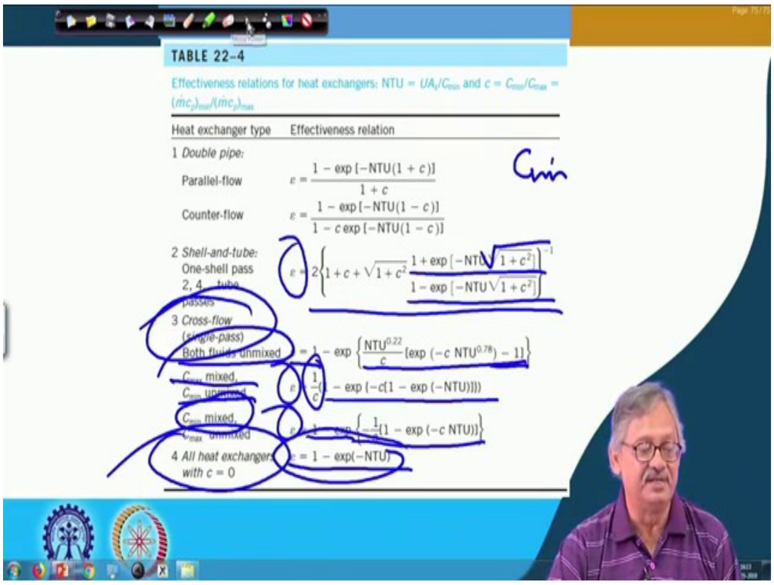

That we can also see from here, that this table says that effectiveness relations for heat exchangers is like that NTU is equals to U A s/ C_{min} and C = C_{min} / C_{max} = m Cp_{min} /m dot Cp_{max}, right.

So, if heat exchanger type is like that double pipe and if the flow is parallel, then the NTU relationship is like this: ε =1 – exp[- NTU (1 +c / 1+ 1+ c)]; where c = C_{min} / C_{max}

right. Similarly for counter flow, the same ε is 1- exp[- NTU (1 - c / 1 – exp[-NTU (1-c)]. For shell and tube one shell pass 2, 4 etcetera tube pass, right shell pass one; that is the external fluid which is going out is having one pass whereas, the other one has 2 passes or 2, 4, 6 whatever passes, right. So, here we can have baffle and do the passes.

Then there ε is 2 (1+ c+ $\sqrt{1+c^2}$) (1- exp[- NTU $\sqrt{1+c^2}$ / 1 – exp[-NTU $\sqrt{1+c^2}$] right. For cross flow where single pass both fluids unmixed right; if C_{max} is mixed then oh for both fluid unmixed ε = 1 - exp[- NTU $^{0.22}$ / c] (exp[- c NTU$^{0.78}$ – 11]. Or if C_{max} is mixed or C_{min} is unmixed; then ε =1/ c (1 exp[- c (1 – exp[- NTU]. Or if C_{min} is mixed and C_{max} is unmixed just the reverse, then ε =1 – exp[- 1/c (1- exp[-c NTU].

If all four heat exchangers with c is equals to or if all heat exchangers with c = 0; then c = 0 means C_{min} is 0, right. So, epsilon is 1 – exp(NTU), 1 – exp[- NTU] right.

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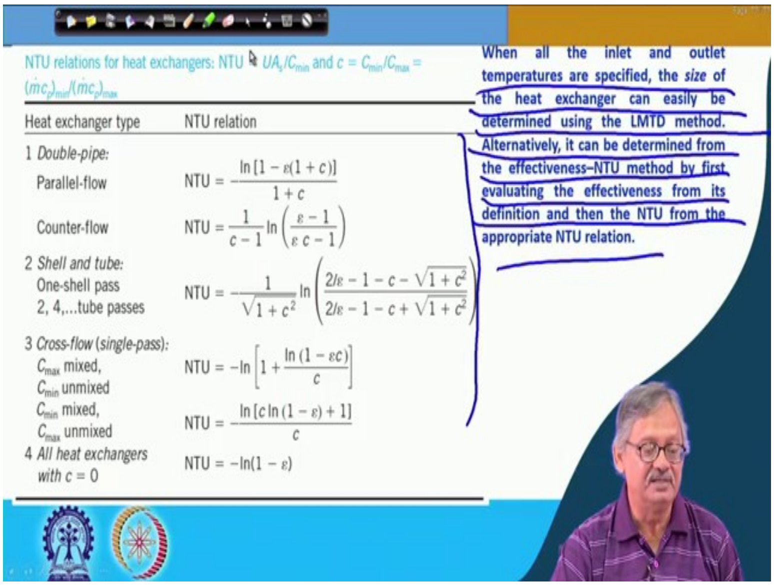

So, we can write, that NTU relations for different double tubes, different heat exchangers type are also like this right. When all the inlet and outlet temperatures are specified, the size of the heat exchanger can easily be determined using the LMTD method. Alternatively, it can be determined from the effectiveness NTU method by first evaluating the effectiveness and from it is definition and then the NTU from the appropriate NTU relations, right.

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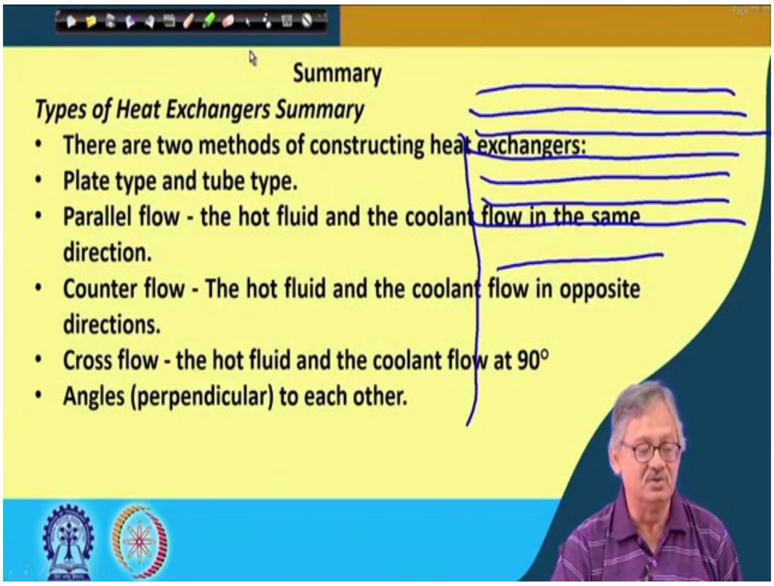

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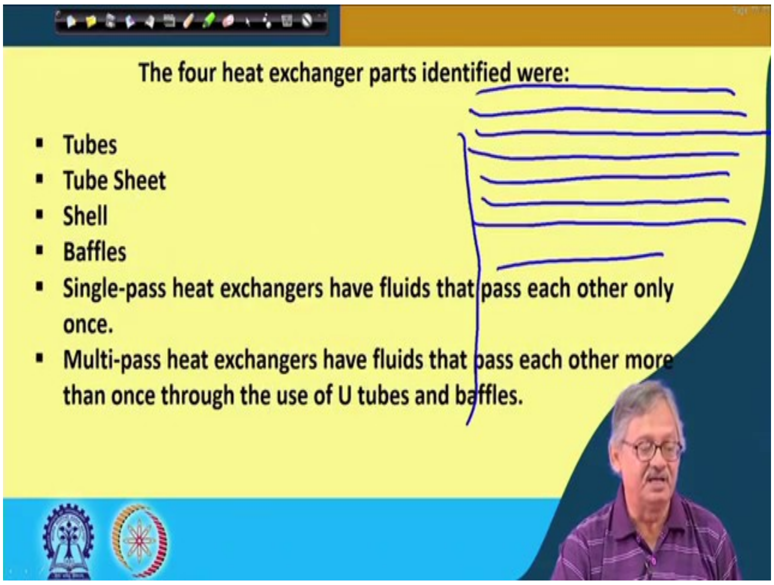

So, this is how we have done the summary and that is where we are coming to the end of this class particularly; where we have done for NTU Number of Transfer Units in terms of effectiveness, right. So, with this let us stop, the time is up so.

Thank you.