**Thermal Operations in Food Process Engineering: Theory and Applications**
**Prof. Tridib Kumar Goswami**
**Department of Agricultural and Food Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 45**
**Heat Exchangers (Contd.)**

Good morning we are then dealing with the types of heat exchangers, 'right'. We have already said a lot about tabular type heat exchanger then plate type heat exchangers.

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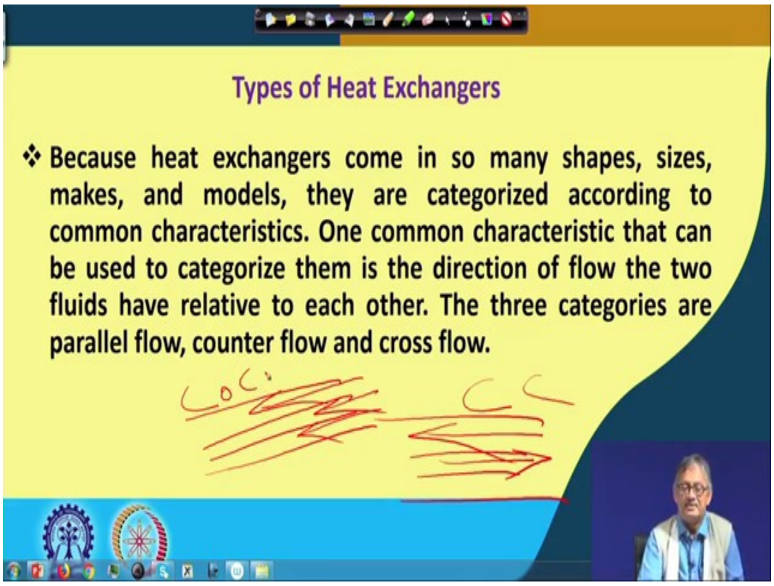


So, in our this 45th class we still continue with the Heat Exchangers, hopefully we may be required to do some more because we have not come across yet the heat transfer analysis of heat exchangers and there are some more things very important like log mean temperature difference like number of transfer units or efficiency of the heat exchangers these things we will do in detail also, 'right'.

So, maybe subsequently is number of classes we may be requiring to handle it because our objective is to do as much heat transfer coverage as possible along with definitely some explanations of the systems some explanation on the operations. So, those things we are doing parallelly side by side, 'right'. So, to do these types of heat exchangers we also can say because of the heat exchangers come to many shapes sizes make and models they are categorized according to common characteristics.

One common characteristic that can be used to categorize them is the direction of flow the two fluids have relative to each other, ‘right’.

So, as we are saying repeatedly that if we have say a tabular type heat exchanger if this is the tube van shell. So, if this is happening one fluid and if this is happening the other fluid flow then we can we call it to a counter current, ‘right’ and if this heat exchanger we have a liquid is flowing in this direction and the another liquid is flowing outside in this direction same direction then we call it to be co current, ‘right’.

So, depending on the direction of the flow and many other factors as we said shape, size make, model all these determine or categorize the types of heat exchangers. So, one such that on the basis of the direction of the flow of the two fluids with respect to each other the heat exchangers are also classified ‘right’. And for that there are three categories and they are named as parallel flow, counter flow and cross flow, ‘right’; parallel flow, counter flow and cross flow type heat exchangers.

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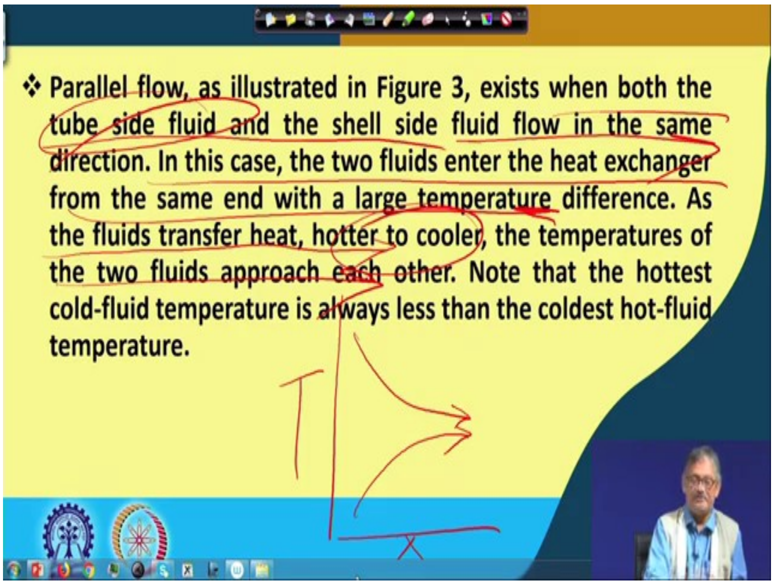

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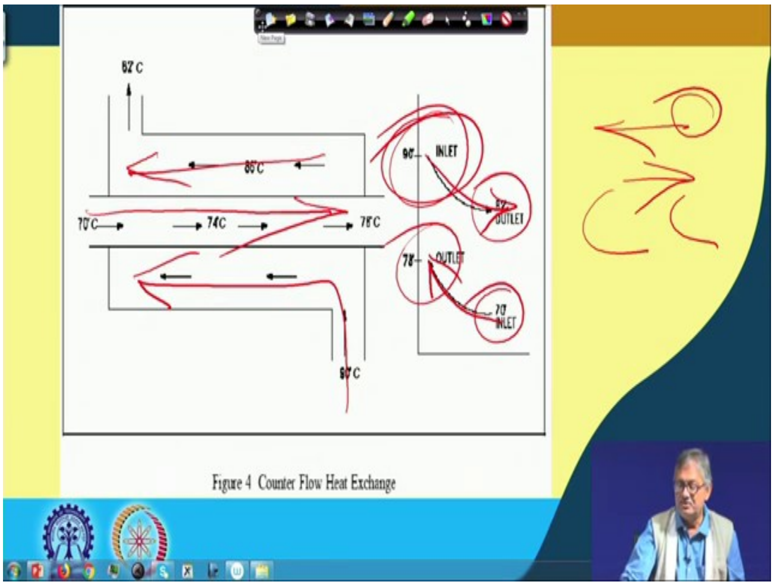


In the parallel flow that let us show it in the figure; this is the figure that in the parallel flow it is like that the fluid is entering through this and another fluid is entering and going out like this, ‘right’. So, both the fluids are in parallel direction, ‘right’ and in that case the distribution of temperature of the two fluids will be like this, ‘right’. So, this is one end that is hot fluid this is the other end that is the cool fluid, ‘right’ and they will exit in the same direction at different temperatures than their entrance, ‘right’.

So, this is called parallel flow, ‘right’ and if we look at its features that this exist when both the tube and fluid tube side and fluid and the shell side fluid flow in the same direction. In this case the two fluids enter the heat exchanger from the same end with a large temperature difference. As a result as the fluids transfer heat hotter to cooler the temperature of the two fluids they approach each other, ‘right’, that is why we showed that this and this these are the two temperature distribution of the fluid this is the temperature and this is the distance, ‘right’.

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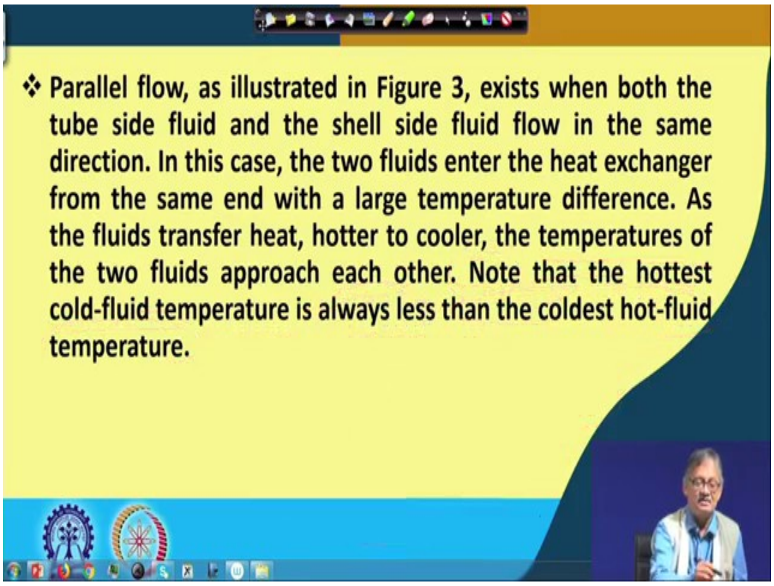


So, if that is true then it has to be noted that the hottest cold fluid temperature is always less than the coldest hot fluid temperature what does it mean that again if we look at the temperature distribution. So, we said this was the inlet of the hot fluid, this is h inlet and this is h outlet and this is cold inlet and this is cold outlet, ‘right’. So, what we said to be noted that the hottest cold fluid, ‘right’, this is the cool fluid that is the hottest air, ‘right’ is always less than the coldest hot fluid that is this is the hot fluid is coldest point is here.

So, that is always higher than the outlet of the coldest hot fluid, ‘right’. So, this you have to keep in mind that this temperature can never be less than this temperature, ‘right’. So, this is the basic feature of the co current heat exchanger.

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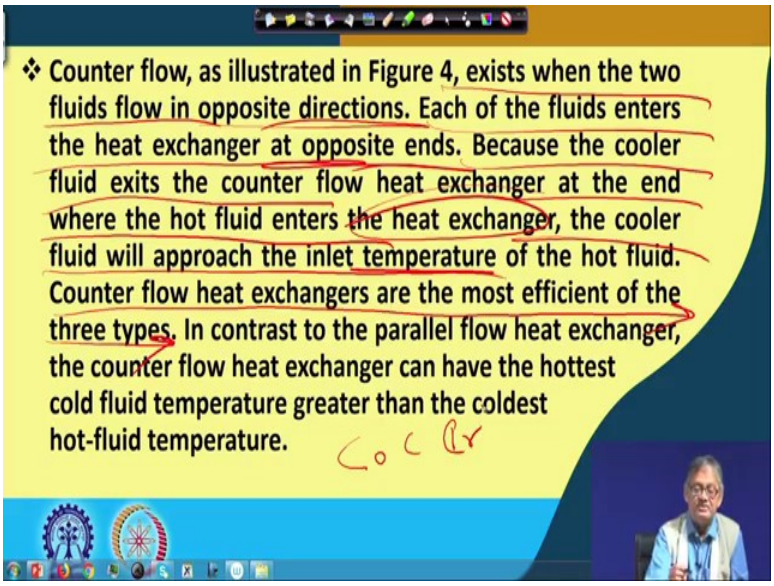


Then if we look at the other that is called counter current before we go into the features let us look into the flow pattern. Flow pattern is like this one fluid is moving this way and the other fluid is moving this way, 'right'.

So, the two flows are in opposite direction that is why it is called counter current, 'right' and if we look at the temperature distribution. So, this is like that and this is like that, 'right'. So, this is the outlet of the hot fluid, inlet of the hot fluid and this is the inlet of the hot cold fluid and outlet of the cold fluid, 'right' and this means that the inlet of the hot and cold fluid are not from the same direction in the opposite direction. Similarly, the outlet of the hot and cold fluid and again not on the same direction, but from the opposite direction or in the reverse direction or reverse point, 'right'.

So, if that be true let us look into the features of this counter current heat exchanger and that says counter flow as we have just seen exist when the two fluids flow in opposite directions each of the fluids enters the heat exchanger at opposite ends because the cooler fluid exist in the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger the cooler fluid will approach the inlet temperature of the hot fluid.

Similarly, counter flow heat exchangers are the most efficient of the three types that is co, counter and cross, 'right'. So, out of these three counter current is the most effective or efficient, 'right'. As we said here that because the cooler fluid exist the counter flow heat exchanger at the end where the hot fluid enters, the heat exchanger the cooler fluid will approach the inlet temperature of the hot fluid and vice versa the reverse is that this is that cooler fluid inlet approaches the outlet of the hot fluid.

Similarly, the hot fluid inlet is approaching the cold fluid outlet, 'right'. So, that is the vice versa and this is the most efficient, then in contrast to the parallel flow heat exchanger the counter flow heat exchanger can have the hottest cold fluid temperature greater than the coldest hot fluid temperature, 'right'.

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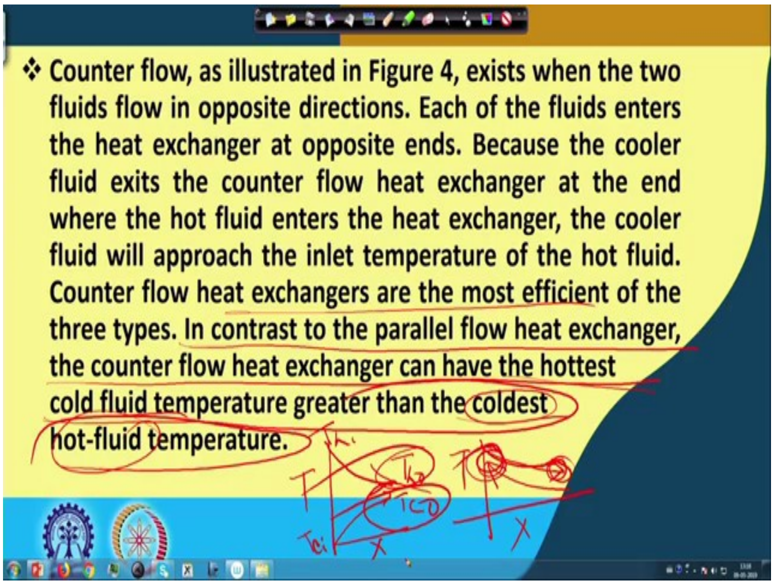


Unlike in the parallel flow if we remember we said that this is the temperature distribution, 'right'. This is temperature and this is the axis, axis means distance, 'right' and we said if it is the a temperature inlet of the hot fluid this is the temperature of the hot fluid out and if it is the temperature of the cold fluid in and if it is the temperature of the cold fluid out then this $T_{co}$ will always be less than $T_{ho}$, 'right'.

This $T_{co}$ will always be less than $T_{co}$ whereas, in the counter current if it is again T and if it is again X that is temperature versus the distance of the heat exchanger. We said that if this is 1 the other one is like that; so, it is always that as we said here the hottest cold fluid, 'right'. So, hottest cold fluid is this the hottest cold fluid temperature is greater than the coldest hot fluid is this.

So, this temperature is less than this temperature; that means, the cold fluid can approach the inlet of the hot fluid or the vice versa the hot fluid can approach the inlet of the cold fluid. So, this is a big achievement and that is why the performance of the counter current heat exchanger is much much better compared to that of the co current or even the cross flow ok.

In many operations it may not be feasible that you always have two cylinders like that or two tubes like that and you allow one fluid to flow like this and in other case you allow the other fluid to flow in the opposite direction. It may not be always possible, ‘right’. It may not be always in the all the cases possible; so, in that case the third option came comes in that not only they co not only the counter, but also some other which is referred to as the cross flow, ‘right’.

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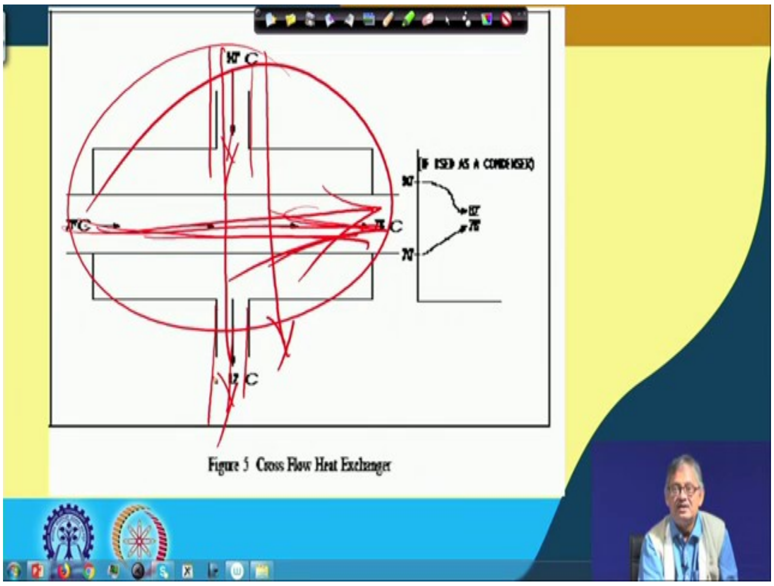


So, that we would look at; so, how does it look like let us look into first that the cross flow liquid or heat exchanger is like this that you have a fluid which is flowing like this and another fluid perpendicular to this flow of the fluid that is flowing like this, ‘right’. So, this type of flow is called cross flow as if this flow is crossing this flow, ‘right’.

So, that is why this is named as cross flow, ‘right’. So, one fluid is getting perpendicular to the other fluid in terms of its flow pattern or flow arrangement, ‘right’. And if we look at the temperature distribution temperature distribution is like this, this is for the hot fluid and this is for the cold fluid.

And in this case also the hottest of the cold fluid cannot be greater than the coldest of the hot fluid, 'right' like in the co current, but in the counter flow we had seen that the temperature of the hot fluid can be or the if the temperature of the hot fluid can be closer to the temperature of the cold fluid in terms of inlet and outlet, 'right' or vice versa.

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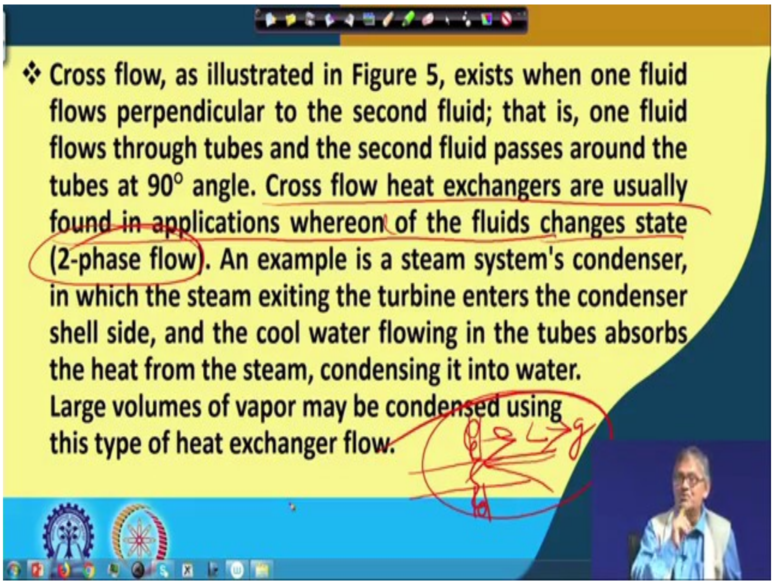


So, if we look at from this the features of this cross flow type of heat exchanger. We see, just now we saw the flow arrangement and the type of heat exchanger is physical appearance, how it looks like that when one fluid flows perpendicular to the second fluid this is called cross flow heat exchanger. That is one fluid flows through tubes and the second fluid passes around the tube at 90° angle. So, that is what is cross flow so, this and 90° this.

So, that two flow are crossing each other that is how the name has come to be cross flow, 'right'. Cross flow heat exchangers are usually found in applications where on or one of the that one of the fluids exchanges state that is there is a two phase flow one of the fluid is exchanging the phase, 'right'; so, this was like this ok. So, it could be that this liquid is exchanging the phase; that means, it came it to be liquid and exit is in the gas whereas, this is in the same liquid, 'right'.

In that case this can be also said to be a cross flow ofcourse, it is not that if it is exchanging the phase is said to be cross flow exchange of the phase can also happen in many other cases, 'right', but this is that where you if we have a cross flow it can also be associated in most of the cases along with the change of the phase of one of the fluids, 'right'. So, an example is steam systems condenser, 'right'.

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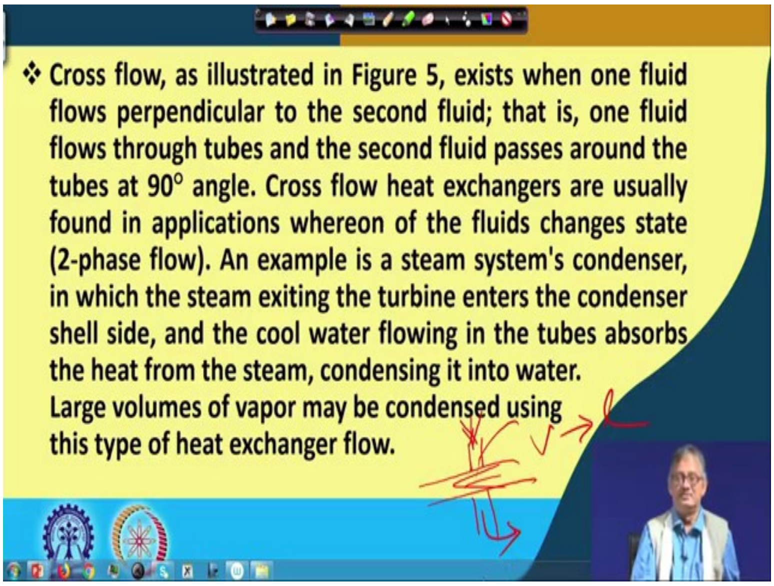


So, again if this was the cross flow, 'right'; of course, this is not there so, you should redo that if this was the cross flow, 'right' and in that case if steam is passing through this. So, steam will condense in it and thereby exchange the heat and it will get from vapor to liquid conversion, 'right'.

So, that is how the steam is being utilized in the condensers, in which steam exiting the turbine enters the condenser shell side and the cool water flowing in the tube absorbs the latent heat or heat from the steam condensing into a condensing heat into water. Large volumes of vapor may be condensed using this type of heat exchangers, 'right', this is what we said steam to liquid or it can be the reversal. So, that liquid to vapor that also can be one example, 'right'.

So, where we have the cross flow it is likely that the cross flow may be associated with the change of the phase of the one of the fluids, 'right'. So, now let us look into the temperature distribution, 'right'.

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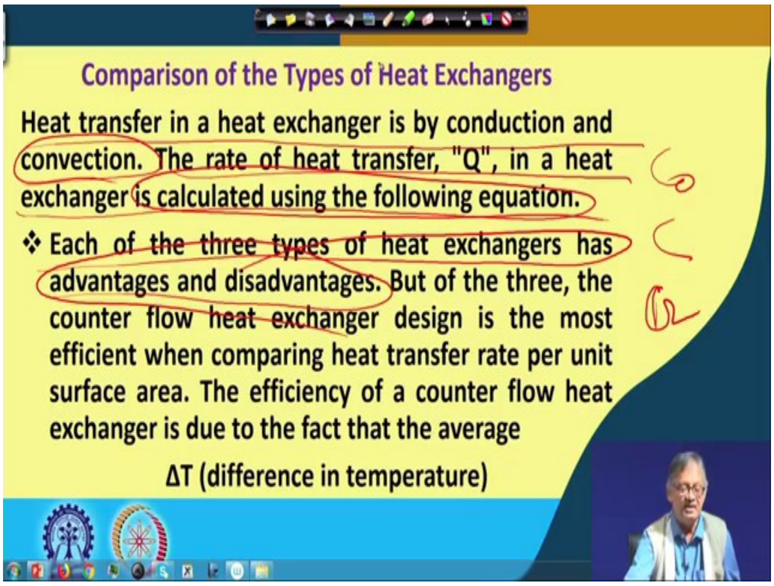


So, comparison of this types of three types of heat exchanger if we look at that heat transfer in a heat exchanger is by conduction and convection. The rate of heat transfer Q in a heat exchanger is calculated using the equations which are coming as follows, ‘right’. Each of the three types of heat exchangers that is co, counter and cross, ‘right’; co, counter and cross, ‘right’. Each of the three heat exchangers has advantages and also disadvantages everywhere if there is a light there is also a dark.

So, some good or some bad is always associated, ‘right’, if there is a good there has is also a bad and that is inevitable. So, here also when you are saying that you have some good thing you may have some bad also, ‘right’. So, that if you look at then you can say that each of the three types of heat exchangers has advantages and disadvantages, but of the three the counter flow heat exchanger design is the most efficient when comparing heat transfer rate per unit surface area.

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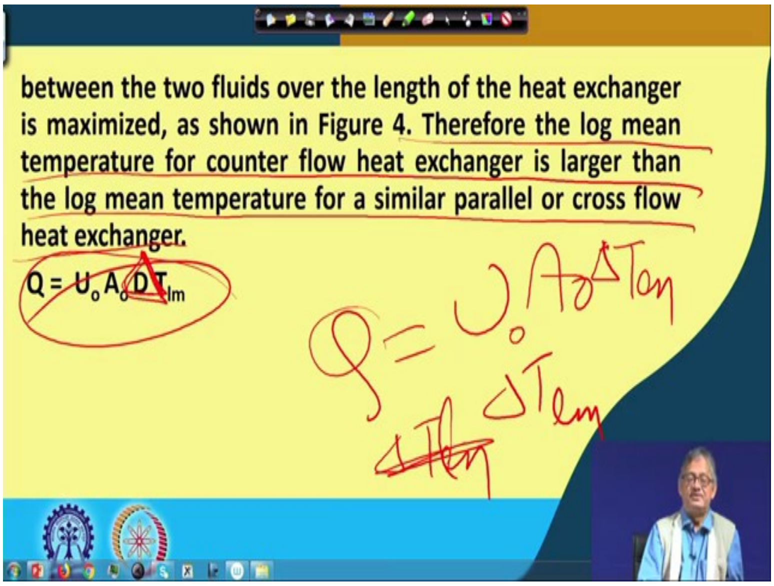


The deficiency of a counter flow heat exchanger is only due to the fact that the average delta T that is the difference in temperature. The average that is the deficiency of the counter flow heat exchanger is that the average $\Delta T$ between the two fluids over the length of the heat exchanger is maximized as, of course, we have shown earlier, 'right'. Where we showed that this is the counter flow, 'right' which showed this that this is the counter flow and one fluid is moving this way and the other fluid is moving this way, 'right'. So, that is the counter flow ok.

So, if that be true then it is true that the that the between the two fluids the length of the heat exchanger is maximized ok. Therefore, the log mean temperature for counter flow heat exchanger is larger than the log mean temperature for a similar parallel or cross flow heat exchanger. So, this is one disadvantage associated with the counter flow heat exchanger, 'right'.

So, here I repeat that the efficiency of a counter flow heat exchanger is due to the fact that the average delta T that is the difference in temperature between the two fluids over the length of the heat exchanger is maximized, 'right'. And therefore, the log mean temperature for counter flow heat exchanger is larger than the log mean temperature for a similar parallel or cross flowed, 'right'.

So, then we can write that equation Q = say $U_o \times A_o \times \Delta T_{lm}$'s this is not D this is $\Delta T_{lm}$, 'right'. So, that it did not take that symbol. So, it is $\Delta T_{lm}$ so; that means, that $\Delta T_{lm}$ is the log mean temperature difference, 'right'. So, $\Delta T_{lm}$ we should write it in better way $\Delta T_{lm}$, 'right'. So, that log mean temperature difference that is true for parallel and counter and cross flow all three flows, 'right'.

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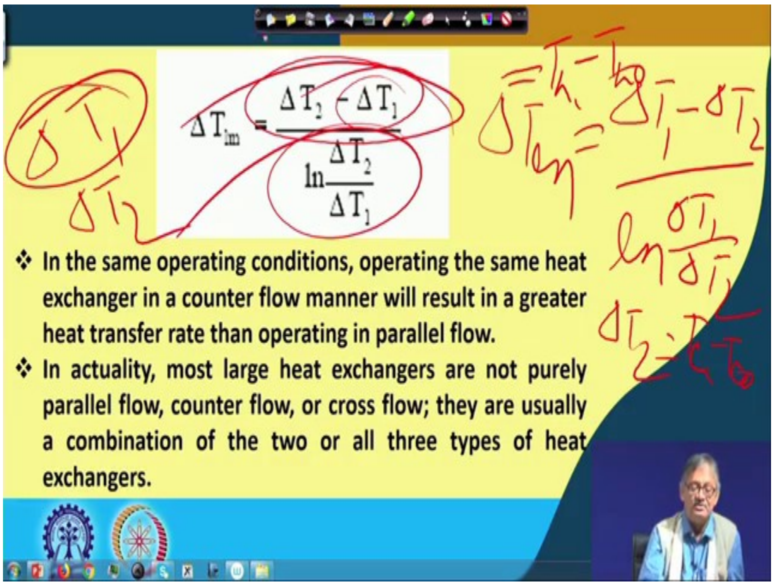


So, if we look at this $\Delta T_{lm}$ that is like that this is $(\Delta T_2 - \Delta T_1) / (\Delta T_2/\Delta T_1)$. Now it can also be that $\Delta T_{lm}$ can be equal to $(\Delta T_2 - \Delta T_1) / \ln (\Delta T_2/\Delta T_1)$. The only thing which you need to do that what is $\Delta T_1$ and what is $\Delta T_2$, that you should define, 'right'. It is not always that this $\Delta T_1$ meaning $T_{hi} - T_{ho}$ or $\Delta T_2$ is always $T_h$ or $T_{ci} - T_{co}$, 'right'. This is not or the reverse vice versa $T_{co} - T_{ci}$ this is not always, 'right'.

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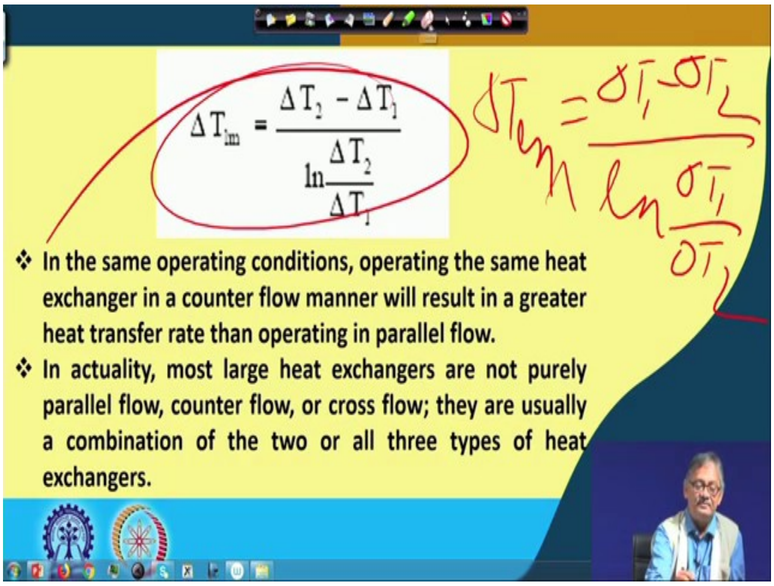


So, that you have to clearly say which one is the $\Delta T$, but it can be like this that $\Delta T_{1m}$ is $(\Delta T_1 - \Delta T_2) / \ln(\Delta T_2/ \Delta T_1)$ or $\Delta T_{1m}$ can also be written as $(\Delta T_1 - \Delta T_2) / \ln(\Delta T_1/\Delta T_2)$, ‘right’.

So, in some of the; in the same operating conditions operating the same heat exchanger in a counter flow manner will result in a greater heat transfer rate than operating in parallel flow that is one that we have already said. In actuality most large heat exchangers are not purely parallel flow or counter flow or cross flow; they are usually a combination of the two or three types of heat exchangers, ‘right’.

It can that is what in plate heat exchanger we said many times that the depending on the flow pattern it can be counter, it can be co or it normally these two in that plate heat exchangers. But, in some cases you may have both these two and the third one that is cross flow also absolute heat exchange with the counter or co may not be in one heat exchanger, ‘right’.

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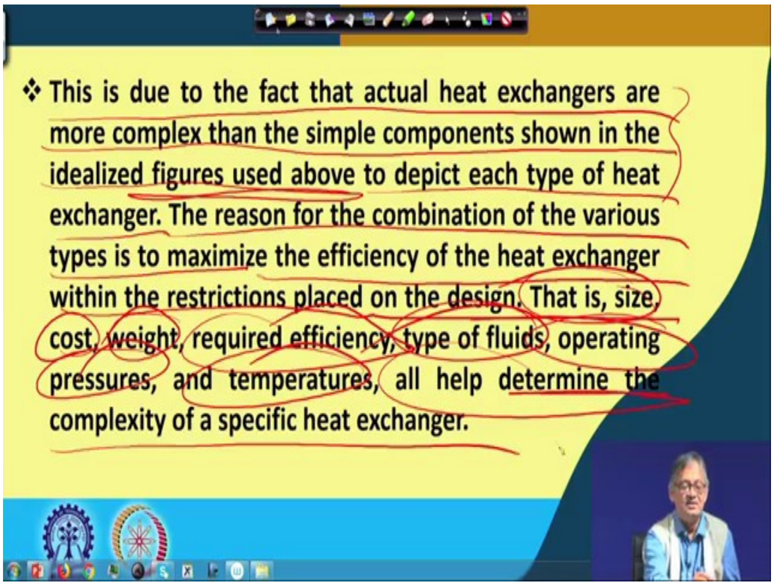


Similarly, we can say this is due to the fact that actual heat exchangers are more complex than the simple components as we have shown, 'right' which are idealized figures and to depict each type of heat exchangers which we have just shown in three pictures.

The reason for the combination of the various types is to maximize the efficiency of the heat exchanger within the restrictions placed on the design and this is the restriction involved are size, cost, weight, required efficiency, type of fluid, operating pressures, temperatures and all help determine the complexity of the specific heat exchanger, 'right'.

So, this is what is about the three types of heat exchangers that is co, counter and parallel. So, we are coming to the end of this class because time is over, but please look into this and next we will do the heat transfer analysis for co current, counter current and the cross flow. And we will also do the heat transfer unit that is net NTU net transfer unit and that will determine the efficiency of the heat exchangers, 'right'.

Thank you.