Heat Exchangers: Fundamentals and Design Analysis

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Lecture - 51
Micro Heat Exchanger

Hello everyone. We are again back for the course Heat Exchangers Fundamentals and Design Analysis. If you recall, we were looking into a special class of heat exchangers that is Micro Heat Exchangers. Let me recapitulate very quickly, micro heat exchangers are heat exchangers, which passages are very narrow. And they are so small that sometimes the fluid flow and heat transfer phenomena follow a physics different from that which we generally encounter in conventional heat exchangers or in passages which are having large dimension large dimensions.

Now, for these then one thing we have to be little bit conversant that is micro scale heat transfer. So, micro scale heat transfer is a topic, which is very vast, and there are many many aspects. So, we have very briefly looked into convection, force convection particularly in micro channels or micro passages. So, there will be issues like sleep, there will be issues like temperature jump. Viscous dissipation cannot be neglected as we often neglect it, in case of flow through conventional size passages.

So, with all these things the relationship for pressure drop and heat transfer that becomes different, so that is what I have explained in my earlier lecture, we have taken some example also to see how it is different. And then, I have told that there a large number of correlation some theories also, which one can employee. This is a class or this is a course of heat exchanger, here we cannot take care of micro scale heat transfer to the fullest extent.

So, only briefly I have mentioned that whenever this kind of topic comes or whenever an engineer is supposed to design micro scale heat exchangers micro heat exchanger, then he has to be little bit careful. He has to look for this kind of information, he should not jump into the design analysis, which already he is conversant for the design of conventional heat exchangers. So, this is the thing which I have covered in our last few lectures.

And then, I have shown some sort of micro channels one or two examples of micro channels. And then, I have told that particularly gas flow we are concerned, because many of the attributes, which we call the attributes of micro fluidics that is found during gas flow through narrow sized, narrow channels or micro channels. Some classifications etcetera we have told some non-dimensional numbers we have introduced.

And then, we are almost towards the end of this discussion. Now, we like to see some heat exchangers, which are micro heat exchangers. Some attributes again due to due to the paucity of time as you have to cover many other topics. So, we will be very brief, and some typical heat exchanger I will show you, and discuss their speciality as micro heat exchangers.

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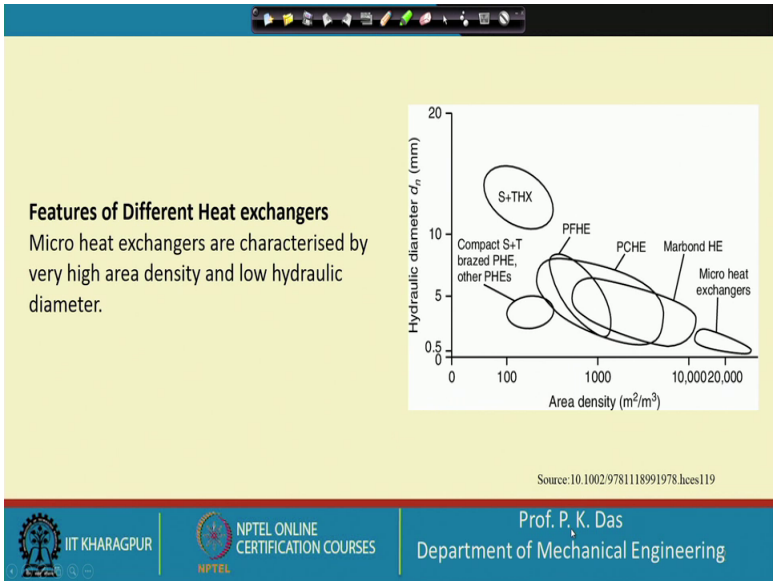

Let us first look into this diagram, which has been taken from a source from a paper. And here two things are given that is area density and hydraulic diameter. And then different type of heat exchangers, which are commonly in use in engineering practice are shown here. So, we can see shell and tube heat exchanger, which is one of the oldest type heat exchanger very common heat exchanger. So, obviously it is area density will be low, and it is hydraulic diameter will be high, so here we can get it.

Then we can have compact shell and tube heat exchanger, plate heat exchangers, base plate heat exchangers etcetera. So, where we are having a smaller hydraulic diameter, then there are certain overlapping region where different kind of heat exchanger come.

So, what we are having plate fin heat exchangers, so compactness have increased. So, I have told for gas flow the area density that is metre square per metre cube area density per unit volume. If that crosses a number 700 roughly, then we call it compact heat exchanger. So, you see it falls in the compact heat exchanger region that is P H PFHE plate fin heat exchanger.

And I think some discussion regarding plate fin heat exchanger has already been given in this course. Then we have got PCHE, so this is again another kind of heat exchanger, printed circuit heat exchanger and that covers again a large range. Obviously, it covers also the range of compact heat exchanger.

And then, we have got Marbond heat exchanger, this is a special kind of heat exchanger; this is made out of plate. So, it has got a lot of similarities or some similarities with plate type heat exchanger. And some similarity with printed circuit heat exchanger, but the passages on the plate they are made by photo chemical etching very special process. So, we can get in narrower passages, and then they are diffusion bonded or a suitable bonding technique can be adopted.

Then we are getting micro heat exchanger. So, micro heat exchanger you see the area density is very high that means, 20,000 meter square per meter cube very high um area density. And at the same time hydraulic diameter is also very small, what we can see here that the hydraulic diameter is very small. So, it is again not a very large range. So far whatever micro heat exchanger has been developed, so that does not cover a very large range, but this covers a very special range, where we are having a very large area density.

This I have told number of times, I like to stress once again that micro heat exchangers and compact heat exchangers are basically having a very large amount of overlap. One can probably safely say that all micro heat exchangers are compact heat exchanger, of course there could be there could be there could be some sort of exception. But, most of the cases micro heat exchangers are compact heat exchangers, but at the same time the compact heat exchanger there could be very large compact heat exchanger like air separation plant, we can have a very large compact heat exchanger.

In some clean energy system, we can have a very large compact heat exchanger, whereas micro heat exchangers are small. They are of special type and they handle very very less amount of fluid very less amount of fluid flow rate through the micro heat exchanger will

be small. So, these are actually notional differences. Obviously, the name which has been given from time to time to different types of heat exchangers that will so they are could be some sort of a controversy. Even the ranges I have shown there could be some sort of a controversy.

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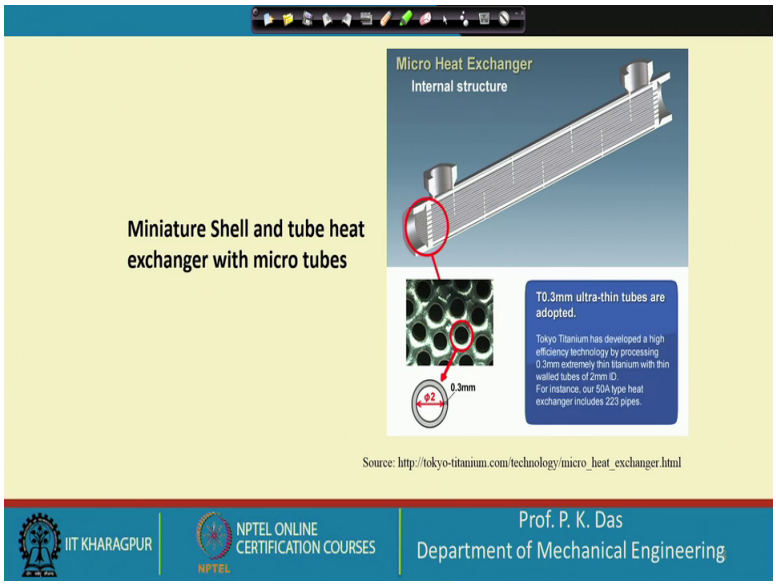

So, with this let us go to different kind of micro heat exchangers. This micro heat exchanger I have shown at the beginning of this particular topic. So, this is a shell and tube micro heat exchanger or micro shell and tube heat exchangers. So, shell and tube heat exchangers in micro scale are not very common. In compact shell and tube heat exchangers are also not very common though there are certain designs, which can be called compact shell and tube heat exchanger. But, this is a very unique example, this is a very unique example the tubes are micro tubes they their diameter, you can see it is 2 millimetre a diameter. So, this is really very small.

And one definition I have given in some of the earlier slides or earlier lecture that when the diameter is less than 3 millimetre, we can call it a micro heat exchanger or micro channel. So, in that way it is within the scope of that definition. So, it is 2 millimetre diameter tube. Very large number of tubes are there. So, if very large numbers of large numbers of tubes are there very large number of tubes are there, then one can understand that the flow passage between the tube that is also small.

So, what we are getting, we are getting micro passage in the tube side and micro passage in the shell side also. So, here we can see the shell side passage is also very small. So, not only that the tube dimension is very small that is made of, it is made of special material like titanium. And one can see some feature which is there in large shell and tube heat exchanger that we have got the we have got the bar fills, so that the shell side fluid it has to take a zigzag way like this.

So, obviously here we can have a good amount of heat transfer within a compact volume within by using a heat exchanger of small weight. And at the same time one can expect very high rate, high capacity of the heat exchanger, but one thing I think, it goes without saying, but I try to draw your attention as the passages are very narrow. So, there will be considerable amount of pressure drop ok. So, both the shell side and tube side there will be considerable amount of pressure drop.

And another aspect again I like to impress as trace upon that particular point that as the passages are narrow. So, the operation should be as far as practicable fouling free, because if fouling is there and fouling is predominant. Then of course cleaning etcetera, those issue will come and very quickly the heat exchanger it will not be usable, so servicing is also difficult. So, these points we have to keep it in mind. Here I like to say again which I have told earlier that, circular micro passages are not very common, but this is one unique example where we have got a micro heat exchanger with circular passage also. Let us go to the next slide.

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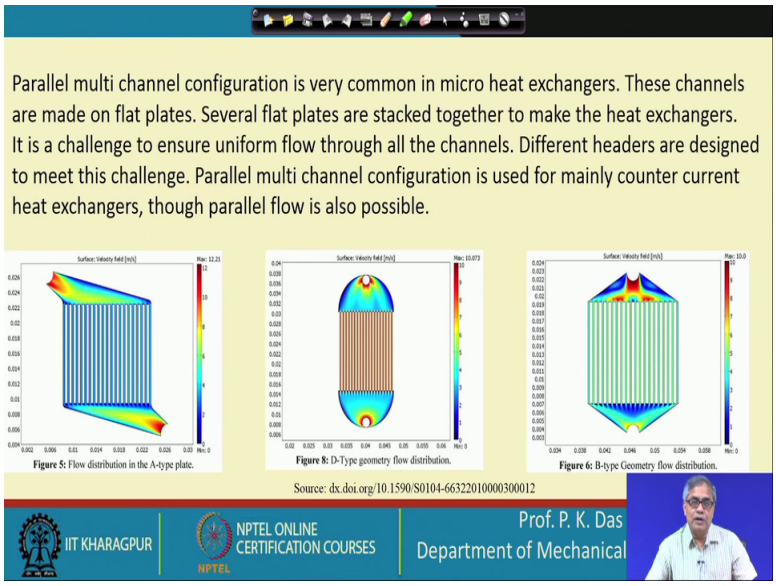

This kind of configuration is quite common in micro heat exchanger. What configuration it is that, it will have number of parallel channels number of parallel channels it will have, so probably it will have a plate, which we are going to see later on that on the plate there will be number of parallel challenges parallel, parallel channels cut. And then on those parallel channels one can have through those parallel channels one can have flow through those parallel channels. And then what one can see that surface area again is very large.

But, you see there is one issue over here that if we have to use the entire surface area with equal effectiveness for heat transfer with equal capacity of heat transfer, then we have to ensure that through each of the individual channel same amount of fluid through fluid passes or the flow distribution there are large number of channels. Let us say there are many channels in this direction. So, there should fluid should pass with uniform velocity or uniform flow rate for each of the channel that should be ensure that is very difficult to ensure, because there will be one fluid inlet, and one fluid outlet.

And due to the resistance of the flow path some of the some of the channel will get more fluid flow, and some of the channel will get less fluid flow. So, this one can call as maldistribution of fluid. Maldistribution of fluid that is there or maldistribution of flow that is there in large size heat exchangers also, but the problem is more accurate sorry more acute in case of small heat exchangers or micro heat exchanger, so that is why

people design different kind of different kind of planar, different kind of header for the for the incoming and outgoing fluid.

So, then we can have some remedy for the maldistribution. If we consider, let us say this is the inlet, this is the outlet ok, before that let me tell you that three configuration whatever you are seeing, this is from a research paper, whose reference is given to here, it shows the numerical modelling, computational modelling, so how this flow distribution is taking place, so that has been described over here. So, here you see three different cases are there. And three different header design for inlet and outlet it is there.

So, now if we consider the resistance, let us say we are considered in this particular channel, so then the fluid is coming over here. So, here it has to cover a small path, then it passes through the channel, but then when it has to go out it has to cover a larger amount of path. If we consider channel at the other extreme end of the heat exchanger or other extreme side opposite side of the heat exchanger, then the incoming fluid passes over a larger distance larger resistance.

Then it passes through the channel or through the passage, and then there is a smaller resistance before it goes to the exit manifold. So, you see more or less the total amount of resistance, which will be encountered by a particular passage that that the designer try to keep constant and with this one can ensure that a good flow distribution will be there. Let us go to the next slide.

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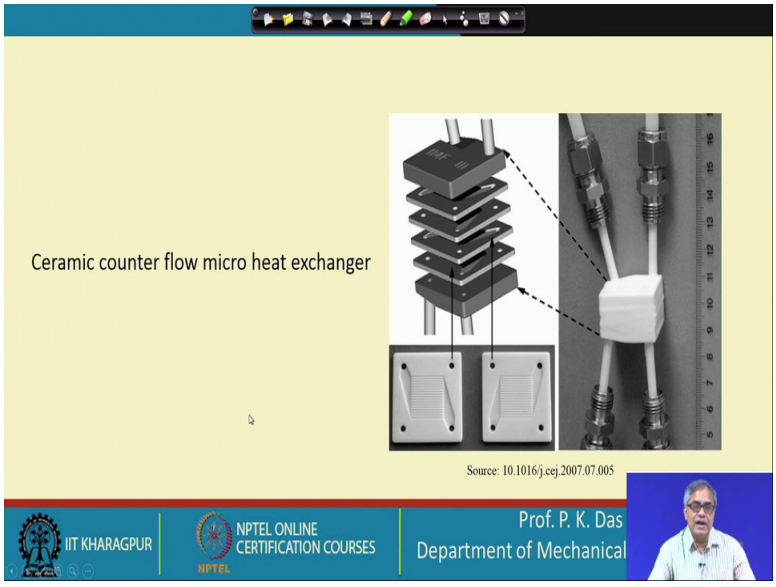

So, here again whatever we have seen in the earlier slide the same thing has been shown that here number of parallel passages. And the plane arms are designed similar to what we have seen in our earlier case. And then here we can get the construction of the heat exchanger. So, here you see there will be number of plates, how many plates we can see 1, 2, 3, 3, 4, four plates we can see.

So, fluids will be passing one particular fluid. Let us say the fluid will be coming like this, and going out like this through the passages a given on one plate. Then over the over it there will be another plate and fluid will be entering like this and going out like this. So, you see it is some sort of counter current kind of arrangement. So, they will be stacked one after another. And at the at the end there will be a copper plate like this, which are little bit thicker and the copper cover plate will also um support the inlet and outlet pipe for the fluid flow.

The design which I have shown that is very common that is generally this is stacked and we have a most of the cases counter current flow, but parallel flow is also possible with some sort of a design modification. This can be for liquid flow, this can be for gas flowing. So, this kind of heat exchanger can be designed and used for your for handling small amount of fluid while having a large amount of heat transfer.

Here you see this is a ceramic counter flow micro heat exchanger. So, as I have told that in micro heat exchanger other than metal different other than metal I mean material other than metal are use materials, so like glass is used, like ceramic is used, like silicon is used. So, these are some of the example. This is one of the example. And again if I draw your attention to the dimension of the heat exchanger, so here from here you can have some idea regarding the dimension of the overall dimension of the heat exchanger. So, you can see this is really small.

So, when we have to handle very clean fluid in small quantity, at same time heat transfer is important, so we can go for micro heat exchanger. Micro heat exchangers has got some other attributes also. In many cases, in micro heat exchanger other than heat exchange other than heat, heat exchange different process requirements or process activities process activities are also conducted.

So, what could be those process activities, which will take place side by side your heat transfer. So, this could be reaction. So, there could be micro reactor, this could be mixing

two different fluid they are mixing together. And even one can have some sort of a separation also and so micro heat exchangers are sometimes specially designed to take care of these activities.

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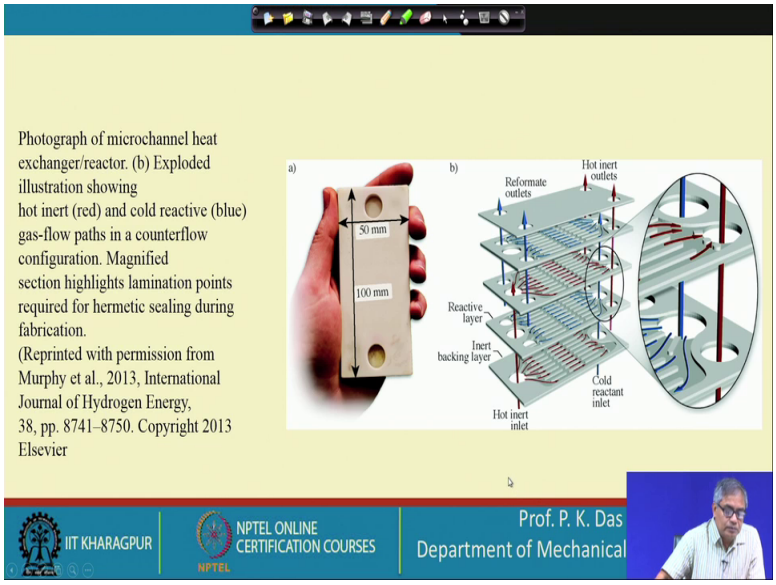

So, if we go to the next slide, here we can see that photograph of a microchannel heat exchanger reactor, heat exchanger come reactor. Exploded illustration that shows hot inlet hot inert this red marks, and cold reactive gas flow path. So, on this side, you can see that hot inert and cold reactive gas flow path these are for different kind of special purposes. Like one can have hydrogen energy programs, one can have some special heat exchanger, but what you need to look into here, first thing you can see the dimensions. So, there is no doubt that this is a small heat exchanger.

Second thing like one can see the construction. And construction is similar to the heat exchanger, which I have shown earlier. So, it will have a plate on the plate there are passages, which are parallel passages. Fluid is coming, and then for the fluid distribution there is path, and you see the path has been made. You see the path has been made here in such a way please have a good look that, so that we can have more or less uniform flow distribution in each of the passages ok.

So, here also you can see that there are some small pieces, which are provided as guide and also as resistance, so that the fluid can be guided. And we can have more or less uniform flow. Then inlet, outlet directions has also been shown that these are inlet and

outlet has also been shown. So, this is how we can have and some details are given with the description provide by the side of this provide provided by the provided by the side of this diagram or a photograph. So, one can have an idea that when you have got combined requirement of heat transfer and reaction let us say, heat transfer and mixing let us say we can sometimes in adsorption absorption. So, those kind of a combined activities can be done with the help of micro heat exchangers. With this let us go to the let us go to the next slide.

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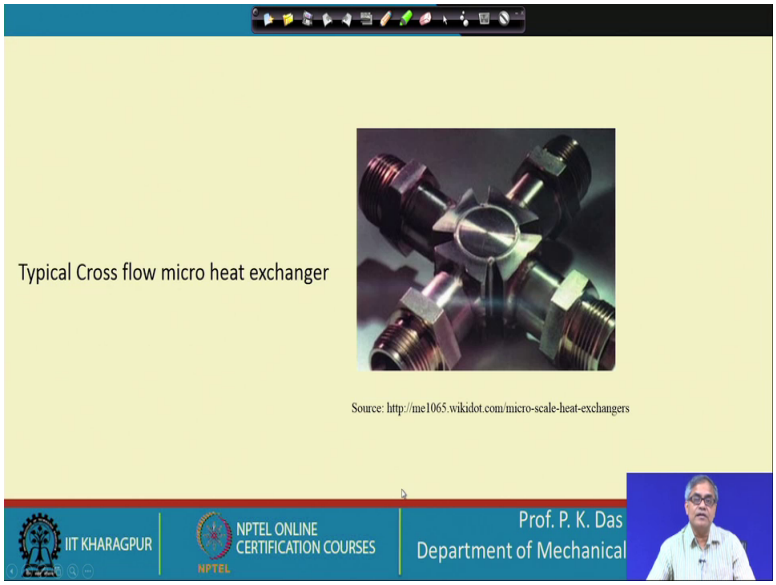

And in the next slide we can see the earlier slide which we have seen that is for I have told that fluid flow is either parallel or counter flow. So, obvious for obvious region sorry for obvious reason, the counter flow configuration will be preferred in many cases. So, here in micro scale heat exchanger or micro heat exchanger is shown which is a cross flow heat exchanger. So, this is a cross flow heat exchanger.

So, one can see that one flow direction will be like this, and another flow direction will be like this which is at 90 degree which are at 90 degree to each other, and one can have some idea that these heat exchanger is really small. So, this a microscale heat exchanger. And this is a very common configuration of cross flow micro heat exchanger and in many application this kind of cross flow micro heat exchanger are used.

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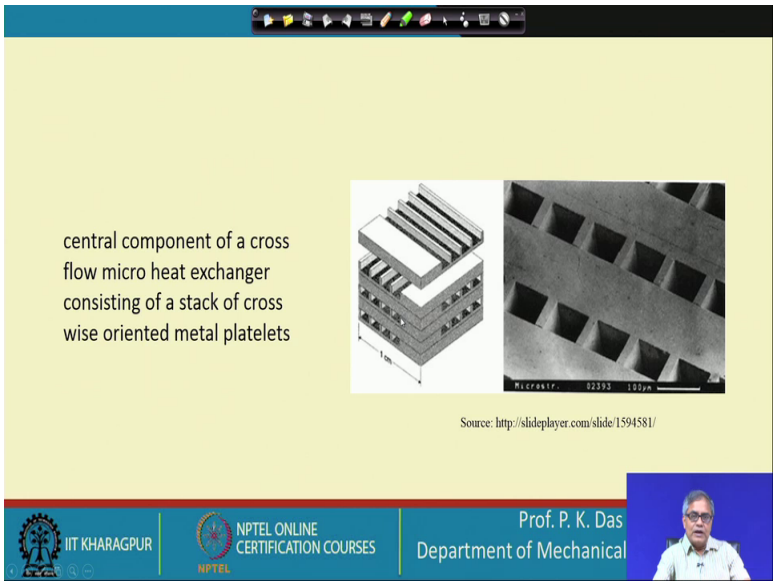

Another example we can see. So, this is another cross flow heat exchanger. Here only heat exchanger core has been shown, central component of a cross flow micro heat exchanger or core of a micro heat exchanger. So, one can see these are one family of passages. So, one fluid flow will be along through these passages. Another fluid will flow through the other passages below it, and that fluid flow is at 90 degree of the screen which is there at the top layer. And then of course, it is only the core it is not the complete heat exchanger, but one can have some idea regarding the regarding the dimension. So, this is really a small heat exchanger.

And then when we are having the core. So, here we can have header. So, here we can have one header, here we can have another header, here we can have the third header. So, something like this, we will have different header at different places. Four headers will be there for a cross flow heat exchanger and we can have conveniently the four headers for this kind of heat exchanger.

Now, let me tell you though I could not take that will be not possible for take up in this short time which we are which we are having to discuss micro scale heat exchanger that what is the speciality of design for this micro scale heat exchanger. One thing let me tell you the conventional heat exchanger the way that is design in some cases only very few cases, we can adopt for micro heat exchanger.

In micro heat exchanger on the other hand if we go back to some of the previous slides let us say we consider this slide. So, there number of passages are there. And in between there are solid wall in between there are solid wall. And due to this configuration what happens of course, one kind of one isothermal condition can be obtained along any line normal to the flow you draw you can get a good isothermal condition or at least you should get the design should be such that it should ensure.

But thing is that that here the solid part that also take a very important role in heat transfer. We cannot in many of the heat exchanger we cannot just consider the fluid only, many cases in conventional design the resistance given by the solid part is neglected or if it is not neglected, it is dealt with some simple equation. Let me tell it sometimes it is dealt with one-dimensional heat conduction equation; many times it is dealt with one-dimensional heat conduction equation. So, here that cannot be done.

Here most of the cases a most of the cases what we have to do that we have to go for a conjugate analysis that may convection within the passages conduction in the solid matrix that we have to do that is one thing. Another thing most of the cases we have to go for 3D analysis and if not at least 2D analysis. So, most of the cases a numerical on computational procedure is needed to assess the performance of this kind of heat exchanger, this is very important to recognise and to understand that the micro heat exchangers the way they are designed that conduction in the solid that plays a very important role.

Maldistribution also plays a very important role; those cannot be neglected in most of the cases. And two dimensionality of the flow field and the temperature field, and sometimes even the three-dimensional variation of temperature and flow field that cannot be ruled out. So, if all these things are there, it is obvious that for micro heat exchanger closed form closed form expression cannot be obtained in most of the cases.

The way we have done the design using LMTD method correction factor or effectiveness in tube method, we have to be bit causes applying those kind of analysis in case of micro heat exchanger; rather in many cases we have to adopt to computational method to assess the performance of heat exchanger. So, this is important to note important to remember and important to apply as the situation one has to judge as an engineer, one has to judge the situation and then one need to apply the method of solution. So, with this I try to end

my discussion on micro heat exchanger. Now, we will from next lecture onward we will switch over to a new topic.

Thank you for your attention.