Heat Exchangers: Fundamentals and Design Analysis
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Lecture - 03
Classification of Heat Exchangers

Hello everyone welcome back to Heat Exchangers: Fundamentals and Design Analysis. Already we have some introduction on heat exchangers and in that I wanted to impress upon you that heat exchangers are of very large variety. There could be wide variation in design construction the arrangement of the fluid flow and application as well as size, shape etcetera.

So, classification of heat exchanger is very important and already we have started towards the end of the last lecture to give some classification of heat exchanger. We will continue with that maybe we will repeat some of the points which we have discussed in our last lecture because, they are very important and then we will proceed with further classification.

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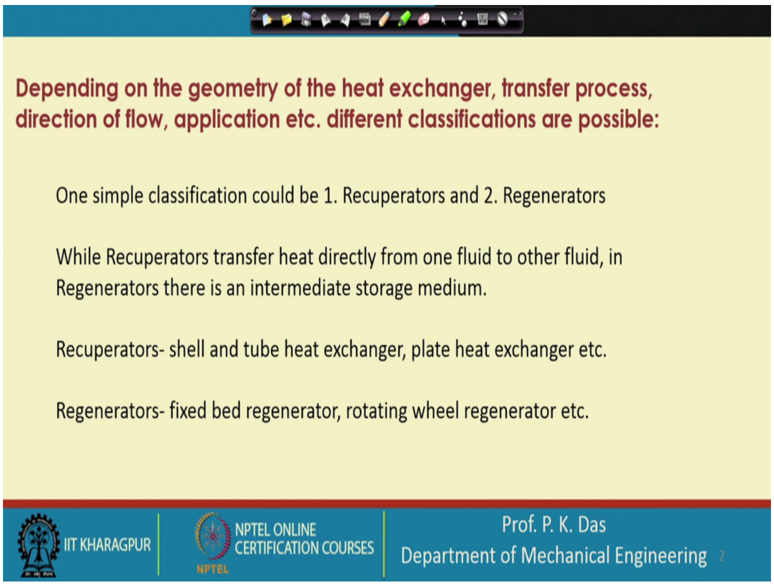

So, initially what I have told that depending on geometry of the heat exchanger, heat transfer process, direction of flow application etcetera different classifications are possible. One simple classification could be that heat exchangers can be divided into two broad classes: recuperates and regenerators. While, regenerators transfers heat directly from one fluid to another fluid of course, these two fluid may not may mix or may not mix with each other. There could be some sort of a separating wall which is a solid wall between these two fluids, but there will be direct transfer of thermal energy from one fluid to another fluid and this is called recuperates.

Most of the heat exchanger we see around us, most of the heat exchangers used in industry are of this class. Examples are shell and tube heat exchanger, plate heat exchanger pin tube heat exchangers and many others. Then regenerators, there is an intermediate medium which will temporarily store thermal energy. So, this is kind of a storage type heat exchanger and there is a third medium in between two fluid streams and well they are also very important though they are not as many in numbers as the recuperates are. So, fixed bed regenerator, rotating bed regenerator and there are other examples we will find as we proceed with the course. So, these are regenerators. Now, if we go to another type of classification.

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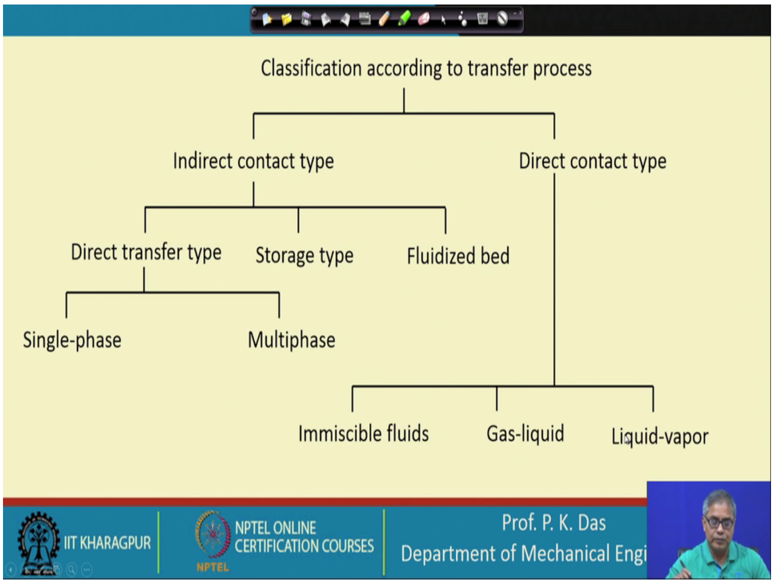

Classification according to transfer process, if you recall this we have already told in our last class may be to give some sort of introduction, but here we can see that the fluid they can come in direct contact with each other. That is we are calling direct contact type and fluid they may not come in direct contact in between there could be some other medium be it a solid, be it a flowing liquid, be it a phase change medium, be it particulate solid particulates for whatever it may be. So, that is your indirect contact.

So, direct transfer type that is that could be again single phase and it could operate in multiphase, then there could be stories type and there could be fluidised bed. So, in all these cases the fluid two fluid streams are not contacting with each other whereas, direct contact type there will be some sort of intermediate sorry immediate mixing between the two fluid stream and that is why there is a limitation what kind of fluid streams can be used.

So, either it could be two invisible fluid; let us say they are two different fluid either in the liquid condition they are invisible or let us say one vapour and another is liquid they are also invisible. So, many of the organic vapours in chemical industries are condensed in connection with water with direct contact with water. So, these are invisible example of invisible fluid contact creating some sort of a direct contact type heat exchanger.

Then there could be gas liquid; so, as you can understand that gas and liquid there is no question of mixing together. So, gas cooling can be done by spraying water I have given one example and then liquid vapour. Liquid vapour, the if we use the same vapour of the liquid then if there is mixing then there is not much problem in many of the application, we can have this kind of direct contact heat exchangers. So, a power plant is a good example the super heater and feed water heater, open type feed water heater are this kind of heat exchanger where steam and water exchange heat and there could be also phase transfer.

So, some of the heat exchangers we will while we are telling you the classification we will discuss and show some sort of description otherwise the other heat exchangers we will deal later on in details. So, please at this moment is it is important to know the types and I also encourage you to such literature to get some information regarding the type of heat exchanger we are discussing during classification.

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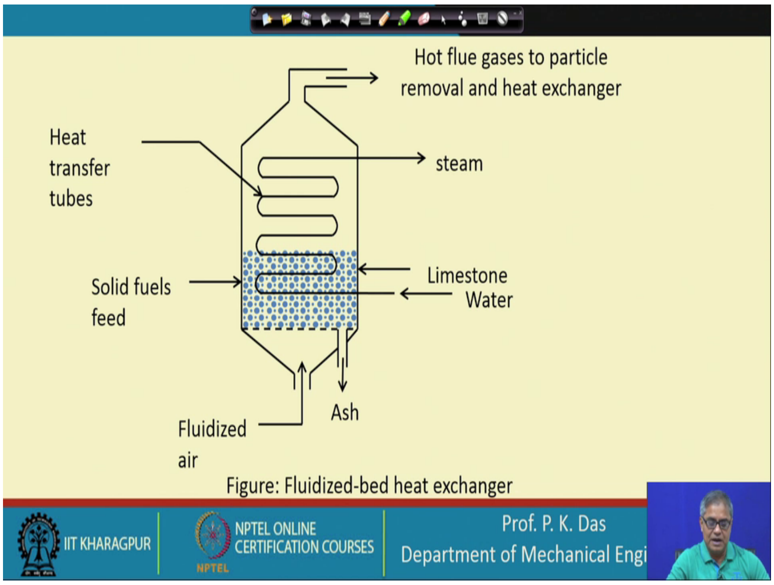

Here only one particular heat exchanger I have picked up from our last classification that is a fluidised bed heat exchanger. So, there could be different type of fluidised bed heat exchanger, but I have taken an example where in a fluidised bed heat exchanger steam is being formed from water.

So, what one can find that here what are enters and out of the serpentine coil or this coil which is having a large length within this heat exchanger so, steam comes out; part of heat it is submerged in some sort of a particulate bed and this particulate bed may contain some inert material and some combustible material. So, through these one can send air and with the air this combustible material may be coldest or some other solid fuel that will burn and produce heat, but that hat will be in this fluidised bed in the solid particulates when those particulates will come in contact with the tube. So, they will transfer heat.

So, you see the first air is heated or the product of combustion that is heated and then that heat through the granular material transferred to the fluid which is passing through the serpentine coil kind of a thing. So, it is an indirect transfer type of device and at the top again hot air is going; so, it can give some more heat for the production of steam. So, this is one example very typical kind of heat exchanger though they are not many in number this kind of heat exchangers are not many in number, but they are very important for energy conversion, recovery of waste heat and burning of low clarifying value fuel environmental protection etcetera. Now, we go to another kind of a classification.

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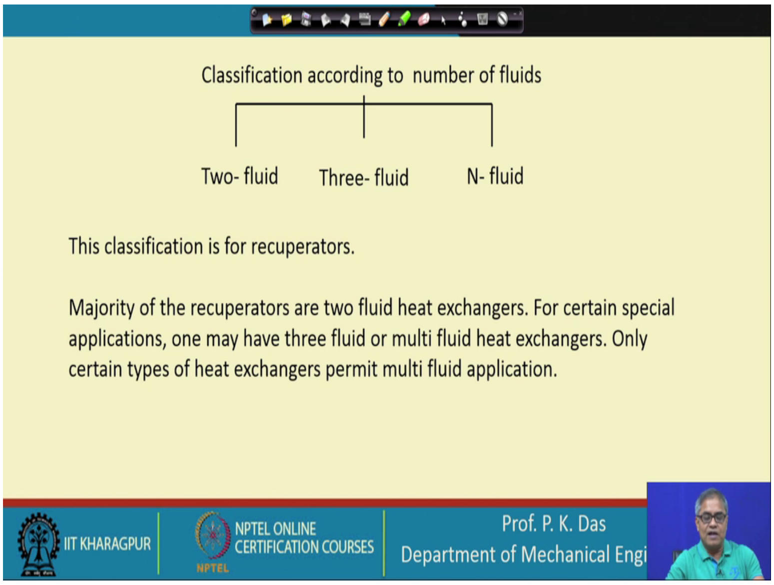

So, here classification according to the number of fluids, I have earlier mentioned that most of the heat exchangers will have two fluids. I again stress upon this particular point, but there could be special heat exchanger where three fluids are involved. Where more number of more than three fluids are involved and those heat exchanger designs are very typical kind of heat exchanger I mean very typical kind of design

I just like to give some example. Majority of the recuperators are two fluid heat exchangers. For certain special application there maybe three fluid or more than three fluid; so, that is what we are going to see.

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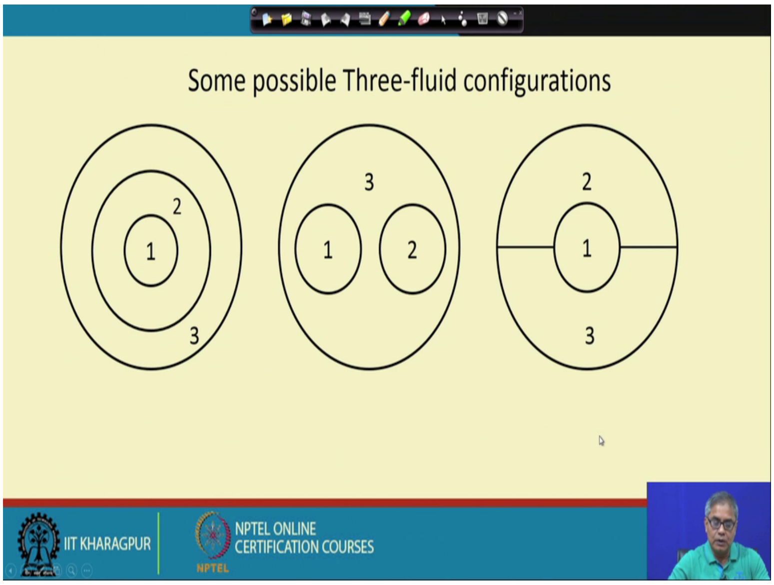

So, here I have schematically shown three heat exchanger, these are all tubular heat exchanger. The metallic envelop is of circular shape, the cross section of the metallic envelop is of circular shape. I have taken the cross section in the first case you can see there are three fluids in through three passages. Central one I have marked as 1, intermediate one is 2 and the peripheral one is 3. So, the intermediate one that is having thermal communication with 1 and 3, but other two fluids like 1 and 3 they are having only one thermal communication.

In the second case there is a shell and in that shell there are two tubes and two tubes are carrying two different fluids, but here thermal communication is there between 1 and 3, 2 and 3, but 3 is communicating both with 1 and 2. So, there could be different design. Third design what we can see that there is a central tube at the top there is another fluid passing and at the bottom there is another fluid passing. So, again here we will have different kind of thermal communication.

So, many design variation could be done these are conceptual some sort of conceptual arrangement I have shown, but let us see in actual heat exchanger how three fluid heat exchanger looks like.

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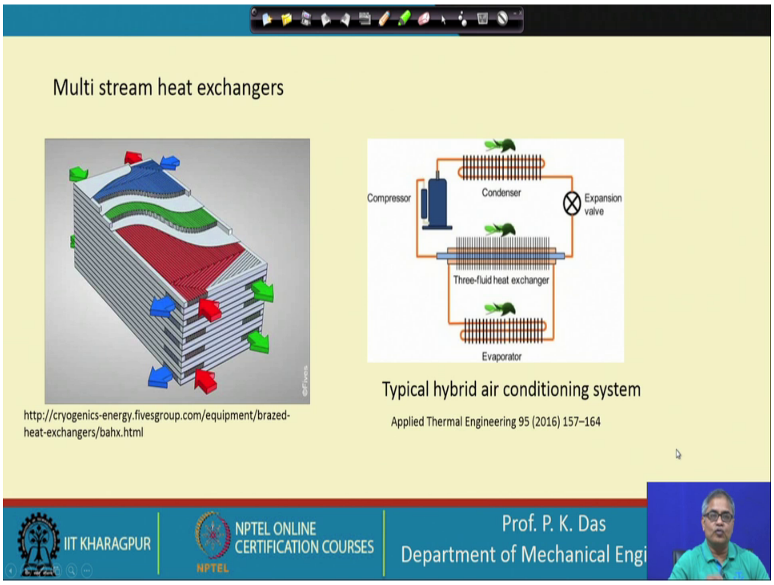

On the left hand side what I have shown on the left hand side I have shown a plate fin heat exchanger. So, in the plate fin heat exchanger there is I mean very versatile I will like to proceed on without giving much details of the plate fin heat exchanger you can take it now that this is the plate fin heat exchanger on the left side and you can see that arrows are of three different colours green, green indicates one particular kind of fluid then we have got blue, blue is indicating another kind or another fluid and then rate that is the third fluid. So, these three fluids are passing through the same heat exchanger.

Then this is one example and plate fin heat exchangers are very good for multi fluid operation. Then on the right hand side we have got one example which could be a hybrid air conditioning system and in that you can see that centrally there is one heat exchanger where two fluids are there. It is it a two fluid type or double tube type of heat exchanger, but at the periphery there are scenes. So; that means, on the periphery we can pass air. So, basically there will be two liquid and one particular sorry one gas which is air and with this three fluid we can have some sort of a three fluid heat exchanger. I have given the reference if somebody is interested this typical and very interesting kind of heat exchanger one can see the details from the reference itself.

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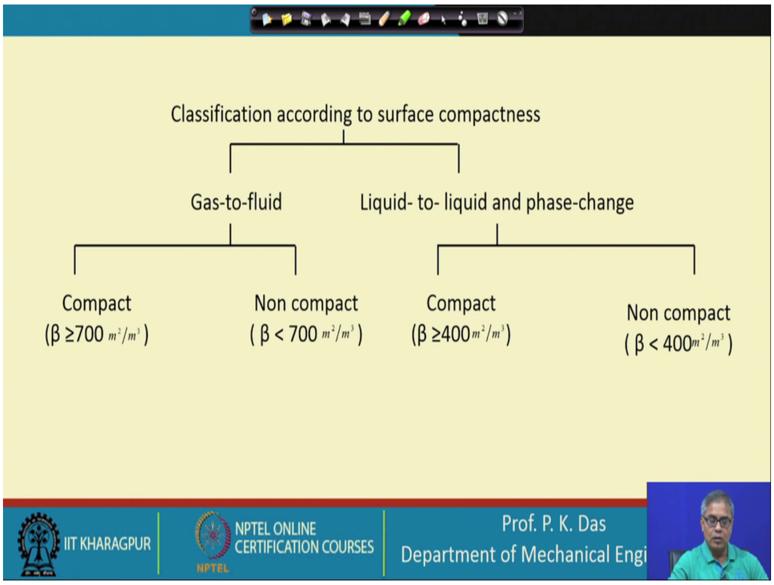

I think here we need to take some time this classification according to the surface compactness you see we will spend some time on compact heat exchanger. But compact heat exchanger this is a terminology which is used for high performance heat exchanger. The high performance could be from different aspects, but one common feature of this heat exchanger that they are having very large surface area within the given heat exchanger volume.

So, to quantify the compactness of the heat exchanger what we do we denote a we have coined a term compactness and we denote it with some sort of a symbol beta. So, you see there is beta. So, beta you see the unit is given meter square by meter cube. So, this is heat transfer area per unit volume of the heat exchanger again one can define it from the hot side or from the cold side.

So, what we will call compact heat exchanger that depends on what kind of fluid we are using. So, if there is heat transfer from gas to some sort of liquid then the compact heat exchanger should have a beta value greater than 700 and if this value beta value is less than 700 then we will call this heat exchanger as a non compact heat exchanger.

Suppose we have got liquid to liquid heat exchanger; that means, both the sides of the heat transfer surface the solid surface we have got liquid or one of the liquid is going through phase change or let us say both of the liquid also can go through phase change. So, then the definition of compactness or the boundary of compactness is slightly different. So, here if beta is greater than 400 meter square per meter cube we will call it a compact heat exchanger and if it is less than 400 meter square per meter cube then we will call it non compact.

One thing I have mentioned earlier and delay I like to mention once again that the most of the things we I have taken from or I have done taking the idea from the book of fundamentals of heat exchanger design by Shah and Sekulic which has been given as the first reference for textbook for this particular course and time to time I have also acknowledged this thing. So, many of the ideas have been taken by the work of Shah by the publication from the publications of Professor R. K. Shah.

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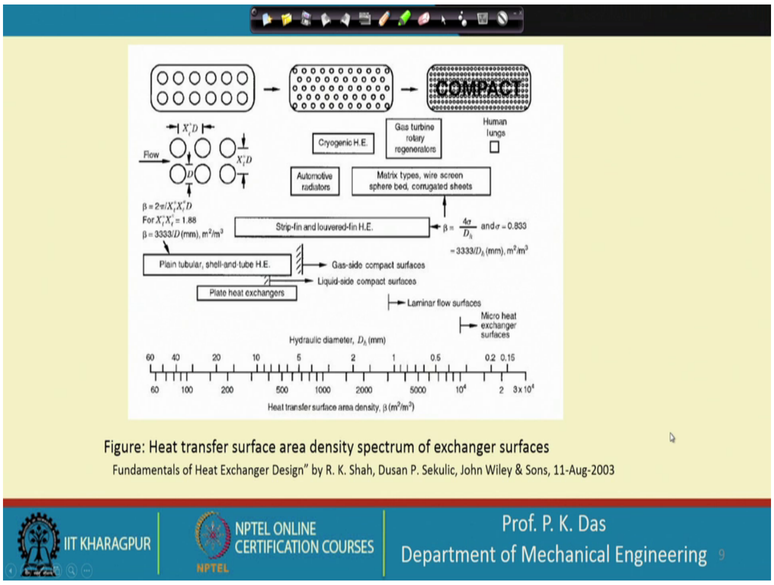

So, next we go to a slide which is very important and one should spend some time here to understand: what is compactness what is compactness in terms of I mean in connection with heat exchanger. So, I have I mean symbolically some heat exchanger structure is shown in the first case there are two fluids let us say this is indicating a two fluid heat exchanger. Let us say through the circle these are tubes through the some fluid is passing and the space in between these tubes there is another kind of fluid another fluid passing it is a general representation, but this kind of representation could be very appropriate for shell and tube heat exchanger which is one of the most widely used heat exchanger in industry. So, this could be the configuration.

Now, keeping the geometrical construct same what we can do, we can increase the number of tubes to a very large extent by reducing the their diameter and the further increase in number of tubes can be shown here. So, as we have a journey from this left hand side to the right hand side we see we are increasing compactness. So, here are some details of the geometry has been shown this X D X cell D X L into D. So, this is kind of a pitch between two tubes and this side there is another pitch between the two tubes. D is the diameter of the tube and from elementary geometry we get beta in this particular with this particular relationship ok.

So, beta can be calculated that is the so, whole idea that knowing the geometry of the heat exchanger, we can calculate beta. Well, then there are certain other things that let us see which are the compact heat exchanger in industry where we have used of compact heat exchanger. Now, it is a very widely used so it will be I mean the list will be quite long where we are using a compact heat exchanger. So, probably here what we find that the earliest use of compact heat exchanger where we had to use compact heat exchanger due to the requirement of the process. So, one we can see cryogenic heat exchanger cryogenic means air liquefaction etcetera are the cryogenic requirement and there we need to have very compact heat exchanger.

Then gas turbine rotary generator that is already I have shown some sort of schematic diagram that is also compact heat exchanger. Then automotive radiators nowadays particularly nowadays the automotive radiators what we are getting or all the heat exchanger used in auto automobiles whatever, we are getting they are very compact. Then matrix type, wire screen, sphere bed, corrugated sheets etcetera these are all your compact heat exchanger. With this there is a comparison of some organism some organ of a living being that is human lung. So, human lung we can see it is much more compact compared to the heat exchanger manmade heat exchanger which has been shown.

Now, human lung is some sort of organ within human body, but it also serves the purpose of exchanging particularly there is lot of mass exchange through human lung and for that also we need large surface area per unit volume. So, this is one of the example how increasing the surface area within a small volume you can have very large rate of exchange ok.

We let us proceed with this description of the slide which is very important. So, here there is again strip fin and louvered heat exchanger. So, this is this falls in the intermediate region. So, what we can see human lung is on one extreme and on another extreme we have got plain tubular shell and tube heat exchanger. So, this is more or less one heat exchanger which is having small surface area per unit volume and if we consider human lung this is one exchanger let us not call it heat exchanger it is having largest amount of surface area within given volume.

Based on a scale this scale has been put at the bottom of the figure now the scale has been made the one side if we go from left to right then we are increasing the compactness. We are increasing the compactness means passages are becoming narrower and narrower passages through which fluid will be flowing that will be become that will become narrower and narrower. So, if it becomes more narrow then hydraulic diameter will reduce.

So, in this scale from left to right hydraulic diameter is reducing; the definition of hydraulic diameter that is known to all of us. So, based on that hydraulic diameter has been calculated and you see here we have got some sort of a relationship between compactness and hydraulic diameter bringing some sort of a sigma factor here the value has been given and then along with this one how the compactness and hydraulic diameter are related. Beta is equal to 3333 by D. So, this is in meter cube per sorry meter square per meter cube. So, this value has been given.

Quite a few other things are there in this figure let us spend some more time. So, as I have told that plain tube plain tubular shell and tube heat exchanger which is most commonly used in large variety of industries which is one of the oldest type of industrial heat exchanger to be evolved or to be invented by human being. So, that is having very less compactness.

And then what we can do this compactness can be increased that if on the gas side we provide some sort of compact surface then plate heat exchanger that is having larger compactness compared to this and this here again we can have some liquid side compact surfaces and then here you see the heat exchangers. So, what we can have in this range starting from less compactness to high compactness plain tubular shell and tube heat exchanger then slightly more compactness plate heat exchanger then plate heat exchanger with different kind of fins. Strip fin and louvered fin heat exchanger automobile radiator there could be different design. Nowadays the design has been changed with micro scale geometrical passages it has come fin geometry and the tube geometry both has changed.

Then matrix type wire fin type heat exchanger in between we have got cryogenic heat exchanger gas turbine rotary regenerator. One kind of heat exchanger which has become very important nowadays that is your micro heat exchanger surfaces this has become very important nowadays. So, with the advent of the manufacturing development in the manufacturing methods; so, we have got different methods of creating very small geometry with kind of large amount of surface area surface variation surface variation will increase the heat transfer coefficient surface area will increase the rate of heat transfer.

So, we have got this kind of variety; that means, micro heat exchanger surface and with this micro heat exchanger surface we can make micro heat exchangers and micro scale heat sinks for electronic industry even in a large heat exchanger. Though, the total volume of the heat exchanger is very large we can go for using this micro scale surface which will increase the compactness of the heat exchanger.

So, you see this is a very important aspect and one needs to understand this one that if we use the compactness of the heat exchanger of if we rather, if we improve the compactness of the heat exchanger the heat transfer increases enormously and then within a small volume primarily within a small volume we can transfer more amount of heat. We will spend some time on compact heat exchanger there the other aspects will come.

But, let me cursorily tell at this point that this is not without any penalty because, when we make it very compact then the along with the complexity of the manufacturing processes, the pressure drop that also increases. And, one has to manage the pressure drop and if the pressure drop increase is justified by other benefit then only one can go for micro I mean very compact heat exchanger. The other thing is that that if the passages are small there could be possibility of choking of these passages. There could be possibility of choking of this passages because, initially a heat exchanger is new and clean, but as the time passes we will have deposition on the wall of the heat transfer surface which is called fouling; which is a very important aspect of heat exchanger time to time we will refer to fouling and if time permits we will also try to see that how fouling occurs, how we can restrict fouling etcetera.

So, the compact heat exchanger should use the fluids and should be operated under operating conditions which does not promote fouling. So, this is another important aspect of compact heat exchanger and if that is satisfied then only compact heat exchanger can be used. So, with this I like to end this particular lecture. We will continue with classification of heat exchanger in our next lecture also.

Thank you.