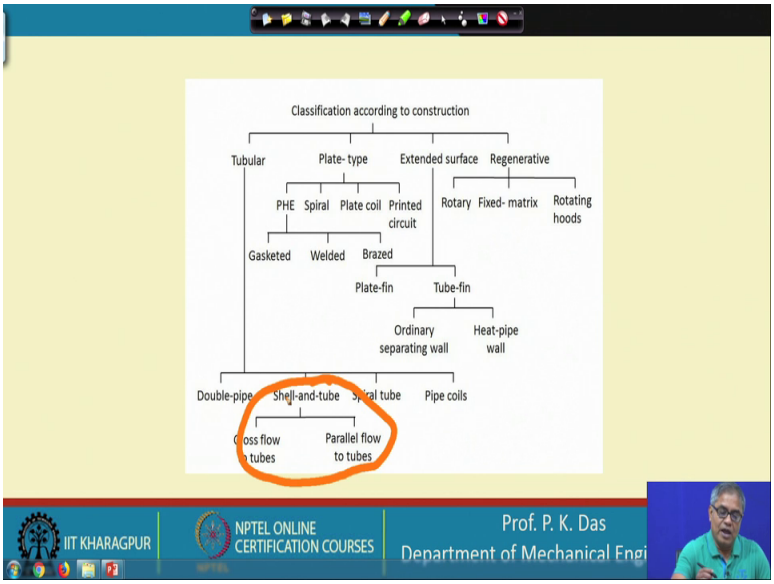
Heat Exchangers: Fundamentals and Design Analysis

Prof. Prasanta Kumar Das
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 04
Classification of Heat Exchangers (Contd.)

Hello participants. So, again we are back in our course on Heat Exchangers: Fundamentals and Design Analysis. We are continuing which the Classification of Heat Exchangers. You see heat exchangers are very large in number. And that is why at the beginning we should have at least some sort of acquaintance with the main types of heat exchangers. And also we should have some idea that there are some special heat exchangers. And that is why we want to spend some time and we want to have this familiarity with the family of heat exchanger through classification, different ways of classification we are showing. Now, we will go to another way of classifying heat exchangers.

(Refer Slide Time: 01:10)



This slide is again very important. Let us spend some slide sorry some time on this particular slide. And here we see classification according to construction. Due to different requirement we have got different construction of heat exchanger. Let us say that there will be I mean there we need heat exchange between 2 liquids which will not be changing their phases.

So, we will have or we will prefer to have one kind of heat exchanger, one particular type construction or geometry of the heat exchanger. Let us say we like to have heat transfer between 2 gas streams, then which we need to have another kind of geometrical construction of the heat exchanger.

So, it depends on many other aspects; only fluid, I have told, but there are other things which also are to be considered. Like, let us say the fluid streams we are handling in the heat exchanger, in one case they are very clean, there will not be any tendency of fouling; we can go for one kind of geometrical construction. In other case, there will be all the possibilities of fouling. So, we have to be careful, so, that we can reduce the tendency of the fouling with the design of the heat exchanger itself.

Or we can keep provision that the heat exchanger can be I mean opening of the heat exchanger, disassembly of the heat exchanger is possible within no time, so that we can clean it and put everything back together to get a clean heat exchanger to start the operation once again.

So, according to geometry we can have different kind of heat exchanger. So, first thing we see the tubular heat exchanger. Tubular construction, a circular a pipe of circular cross section that is very common in industry and we have also the human being has also adopted the same thing in the design of heat exchanger from very early days.

So, tubular heat exchanger, the simplest type could be a double pipe. And I have shown in my in one of my earlier lecture show, either it is called double pipe heat exchanger or tube in tube heat exchanger. So, there is a central tube and there is another tube surrounding it. So, we have a double type heat exchanger double tube heat exchanger sorry double pipe heat exchanger.

The next modification of double pipe heat exchanger, improvement for higher capacity is shell and tube heat exchanger. So, in this case there is an outer shell just like before, but inside instead of a single tube there are number of tubes. So, through the shell side some fluid passes and through the tube side some other fluid passes.

So, shell and tube heat exchanger, let me tell you that this is one of the most important heat exchanger because of their number used in the industry. So, very large number of shell and tube heat exchangers are used in the industry and again shell and tube heat

exchanger there could be variation of internal and providing suitable internal geometrical construction. We can have cross flow to the tube by the shell side or we can have shell side flow parallel to the tubes. So, parallel flow and cross flow you can have.

Now, it is very important to have some idea regarding the shell and tube heat exchanger, but thing is that, I do not like to do it at this moment because of paucity of time. So, what we will do this, shell and tube heat exchanger we will take it in very detail later on. So, just for the time being you know that there is a shell, within which there will be number of tubes and then one kind of fluid will pass through this shell side and another fluid will pass through the tube side, but there could be very large number of variation to this basic design which we will learn later on.

Then there could be spiral tube heat exchanger, tube that is in the form of spiral. There could be pipe coils. So, I mean to increase the area within a given length, all this spiral tube and the coil tube are taken; even a coil tube can be taken within a cell. So, there are different kind of variation in the tubular geometry.

Let me mention a few things, though these are not without exception, that generally tubular heat exchanger we will find if 2 sides there are liquid. So, in many cases tubular heat exchangers are preferred. As I have told that one should not think that there are no exceptions there are exceptions, but in most of the cases, if fluid is passing I mean passing fluid is liquid then we prefer the tubular geometry. Tubular geometry can withstand higher pressure that is one advantage and generally when liquid flow is there could be high pressure. And tubular geometry also gives very good sealing. So, sealing is not a problem, liquid leakage will not a will not be a problem. So, that is why you are tubular geometry is preferred, when there are 2 liquids.

Then the next type of heat exchanger or next type of geometry, which we can think of is plate type; you see this is plate type. So, PHE, Plate Heat Exchanger very important kind of heat exchanger. And there could be different construction gasketed plate heat exchanger, welded plate heat exchanger, brazed plate heat exchanger. Plate heat exchanger also we are going to spend some time. So, you can get some idea regarding the plate heat exchanger when we will do that.

Then spiral plate heat exchanger, this is another variation. Very though it is not used very widely, but it is very important kind of heat exchanger. Good amount of heat exchange

between 2 streams can be opted by spiral plate exchanger. Then plate coil heat exchanger and printed circuit heat exchanger; this is again one heat exchanger which is very unique and large amount of heat transfer is possible though they are not as widely used as your plate heat exchanger or plate fin heat exchanger.

Then we are having extended surface. What is extended surface? On a surface, I mean, a surface generally take text part in heat transfer, particularly convective heat transfer and more the surface area more is the heat transfer. Now what is done? The basic surface, we can increase its area by providing by providing extended surface to the primary surface or to the based surface. These extended surfaces are technically known as fins. So, fins are very commonly provided to heat exchange surface to improve the heat transfer rate, but primarily by increasing the area of heat transfer surface.

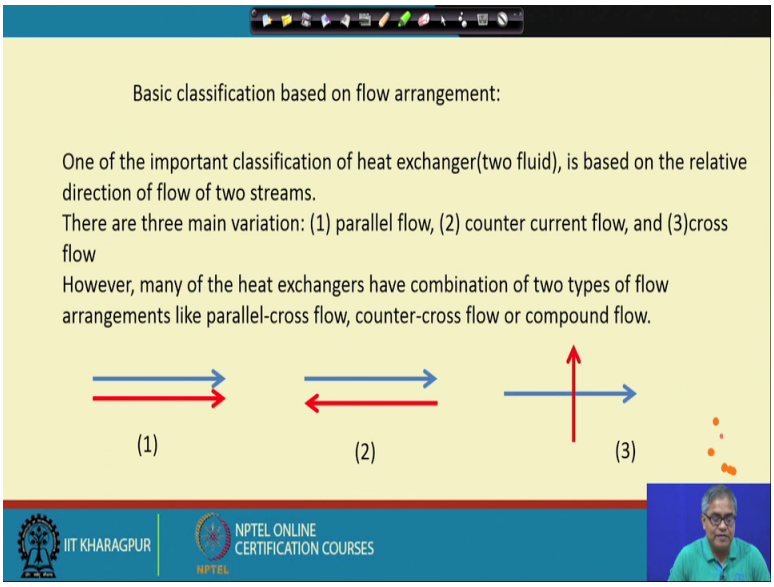
Now, again here let me tell you one thing, though there are exception, generally when there is a gas flow over the surface, we want to increase the heat transfer area by providing fins. So, this is for the gas side surface. And then you see that we can have plate fin in a plate kind of surface or plain surface we can provide fin. Then tube fin on the external surface of the tube we can provide fin. It is not like that that on internal surface we cannot provide fin, but generally that is less common and those fins are small. Then tube fin ordinary separating wall and heat pipe separating wall.

So, heat pipe is a device probably we will spend some time and that time you can understand what is the working principle of heat pipe or what is the working principle of heat pipe heat exchanger. It is a very efficient device of transferring heat from a point of high temperature to a point of low temperature.

So, here also we can use the extended surfaces or fins. Then regenerative heat exchanger, we can have rotary kind of regenerator, we can have fixed matrix kind of regenerator and we can have rotating hood type of regenerator. Again as we will spend some time on regenerator, I am not giving any description at this moment, but these are important to know that we can have this some sort of different construction in regenerator. And once you know this at this moment, what you can do? In between you can search some literature either from internet or from some book or from the reference which we have provided you. So, that you can have some idea regarding regenerator and their construction before actually we teach it in the class.

So, with this let us go to the next slide.

(Refer Slide Time: 11:50)



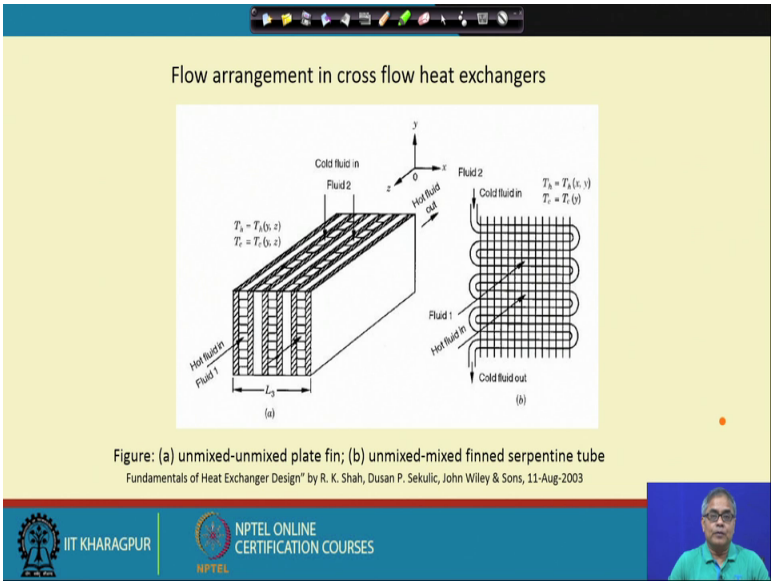
So, basic classification based on flow arrangement. So, there are 2 fluids, I have told most of the heat exchangers are having 2 fluids and most of the fluids are 2 fluid heat exchanger. So, the 2 fluids they will have some direction of flow or rather any fluid will have a direction of flow with respect to the other fluid. Based on that, we have got 3 basic categorisation of the heat exchanger.

The first one is called parallel flow heat exchanger. In this figure also symbolically it is given. Now parallel flow heat exchanger, both the fluids are flowing in the same direction. In a heat exchanger, for both the fluids inlet will be on one side of the heat exchanger length and outlet will be on the other side of the heat exchanger length. Then there will be counter current kind of heat exchanger or counter flow kind of heat exchanger.

So, in this the fluids are flowing in the reverse or in the opposite direction or there could be a cross flow heat exchanger that fluid streams are at 90 degree to each other. Now, in most of the cases or many of the cases we cannot have purely parallel flow, counter flow or cross flow. We can have cross parallel flow or counter cross flow. So, those kind of combination or compound flow where you cannot define the flow direction changes number of times in the length of the heat exchanger or in the volume of the heat exchanger.

But for basic analysis of heat exchanger, basic categorisation of the heat transfer mechanism, or rather how we can mathematically analysed them. These 3 descriptions are very important. That is parallel flow heat exchanger and counter flow heat exchanger cross flow heat exchanger. So, we will keep this thing in mind and see let us see what are the different variation possible. So, let us go to the next slide.

(Refer Slide Time: 14:24)



Particularly, cross flow heat exchanger. Let us spend some time on cross flow heat exchanger because there are certain variation in cross flow heat exchanger. So, 2 different type of cross flow heat exchanger has been shown in this slide, in this particular slide. So, you see this is one cross flow heat exchanger; this could be a plate fin heat exchanger. You see there are passages for 2 gas, one hot fluid that is coming through this passages; through this passage hot fluid will come go in, this passage hot fluid will go, in this passage will go. From the top, the cold fluid will come in through this passage and cold fluid will come in through this passage.

They will come out from the bottom of heat exchanger; hot fluid will come out from the backside of the heat exchanger, the way it has been shown. And we are showing the coordinate system which is the rectangular Cartesian and coordinate system x, y and z. And you see in this case the fluid stream they are exchanging, let us say the hot fluid stream hot fluid stream is exchanging heat with the cold fluid stream, but the hot fluid

stream is not mixing with another hot fluid stream. Let us say this hot fluid stream is not mixing with another hot fluid stream.

Similarly, this cold fluid stream is not mixing with another cold fluid stream. So, what will happen when the heat, I mean on the other side of the heat exchanger, the when the hot fluid is coming out it will have some sort of a temperature variation or temperature distribution same is true for the cold fluid cold fluid. When it is coming in it will have uniform temperature distribution, but when it is going come out of the heat exchanger there will be a distribution of temperature that is what has been told here.

Here we can see another very common construction of cross flow heat exchanger. So, here basically there is a serpentine tube through which fluid is flowing, something like this fluid, is flowing through the serpentine tube liquid is flowing. So, it is very suitable for liquid to gas heat exchanger. And then there are fins through which I mean fins are there integral fin to the tube that is there and then fluid flow is passing through this fin passages. Some sort of a flow passage is made by 2 adjacent fins and through that the gas that is passing. Very common kind of example in case of refrigeration, air conditioning and gas flow liquid heat exchanger.

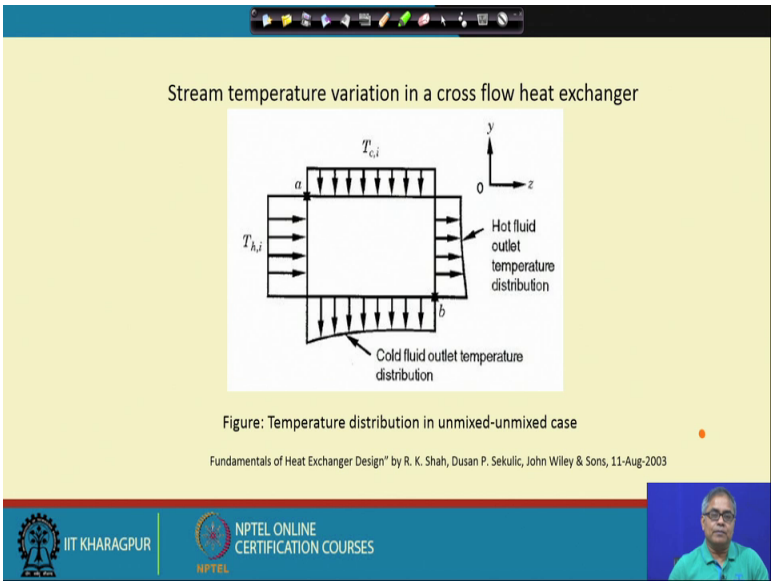
So, here, what will happen? The cold fluid is passing through this, so and cold fluid will come out ultimately with some higher temperature. So, here we will have more or less uniform temperature of the cold fluid, but the hot gas which is plus passing through the fin passage. So, they are not mixing that means, one gas stream is not mixing with the other gas stream.

So, on the other side we will have some sort of a distribution of the hot fluid temperature, we will have some sort of a distribution. So, this is what is very important; that means, in a cross flow heat exchanger, one particular stream may get mixed or it may remain unmixed. And there are different degrees of mixing. So, if it is thoroughly mixed, then as we get uniform temperature at the inlet of a heat exchanger, we will also get uniform temperature at the outlet of heat exchanger. If they are not thoroughly mixed, then there will be a temperature variation. And in our analysis we need to take this temperature variation. So, this is what is important.

And let me tell you one thing that it is always desirable or most of the cases it is desirable to have uniform temperature at the outlet of the heat exchanger, for any stream

of the fluid. Now, in some cases due to the design of the heat exchanger, we cannot have uniform temperature. But, in those cases also there are design modification, so that this uniformity or non-uniformity can be reduced to a minimum. So, we will see some of this is aspect as we proceed.

(Refer Slide Time: 19:46)



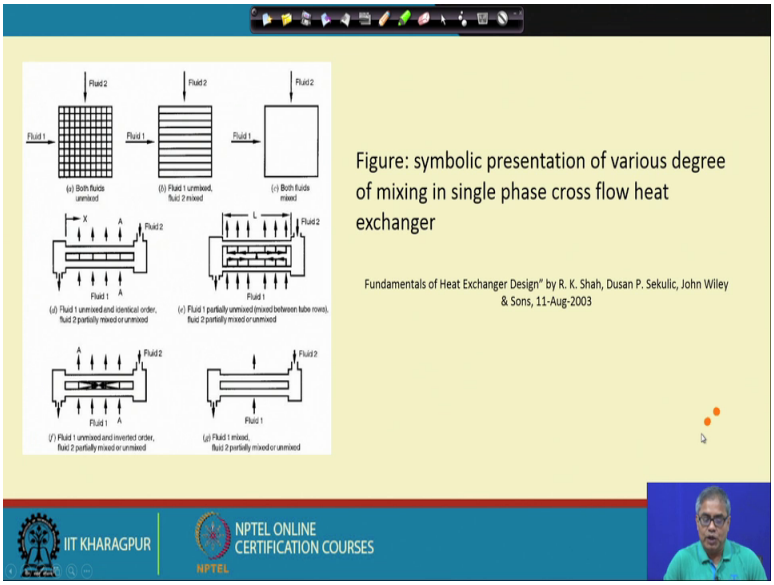
So, here schematically I am showing a cross flow heat exchanger. So, you see this is the cross flow heat exchanger. This side hot fluid is entering uniform temperature; this side cold fluid is entering uniform temperature. So, when the hot fluid sorry when the cold fluid will come out; so cold fluid temperature will increase. So, here we can see that at the exit cold fluid temperature, I am gain some temperature, it has been heated, but maximum gain in temperature is here, where it is in close contact, with the hot fluid.

This hot fluid will initially just after entering, it will come across cold fluid and we will have maximum temperature difference. So, maximum amount of heat transfer will be possible. So, here the cold fluid will have the highest temperature and then it will reduce.

Similarly, the hot fluid will have the lowest temperature at the exit at this point and on this side there will be an increase. So, this is what I have expressed that there will be non-uniformity when there is a cross flow heat exchanger ok. And this non uniformity could be of different products.

So, let us see how, how we can define some more thing regarding this non uniformity in temperature.

(Refer Slide Time: 21:38)



So here symbolically we represent different cases and different type of non-uniformity. The first case left hand side top, here we have shown that both the fluids are unmixed. There are in cross flow heat exchanger there are 2 fluid and both the fluids are unmixed.

In the second case symbolically, we have shown that one fluid is mixed and another fluid is unmixed. And in the third case both the fluid are mixed. So, there are different heat exchanger construction actually the way I have we have shown symbolically thoroughly mixed it cannot happen that way, but there will be different levels of mixing

So, here you see here this is kind of a heat exchanger. So, here the fluid is coming in some sort of inlet plenum, and from there it is passing through the tube and going to the outlet plenum. And ultimately it is going out of the heat exchanger. Let us say this is some sort of a liquid that is passing through these 2 tubes and then let say these are gas. So, that is that is passing through across the tubes and then there are gas passages.

So, here what will happen that liquid will be fluid 1 that is the gas that will unmixed, and that will remain unmixed as it is going out. Fluid 2 of course, it will get partiality mixed or will remain unmixed .Why it will get partiality mixed? Because, here there is a plenum I am sure there could be some sort of a partial mixing.

Then another figure if we see, here, the fluid 1 which is a typically could be a gas, so, that is entering and then here the gas streams after passing across the first tube they are mixing together and then it is going here and passing through the second tube. So, fluid 1 is partially unmixed ok. So, mixed between the tube rows; it is mixing the mixing takes place only between the tube rows. And fluid 2 is partially just like before it is partially mixed or unmixed.

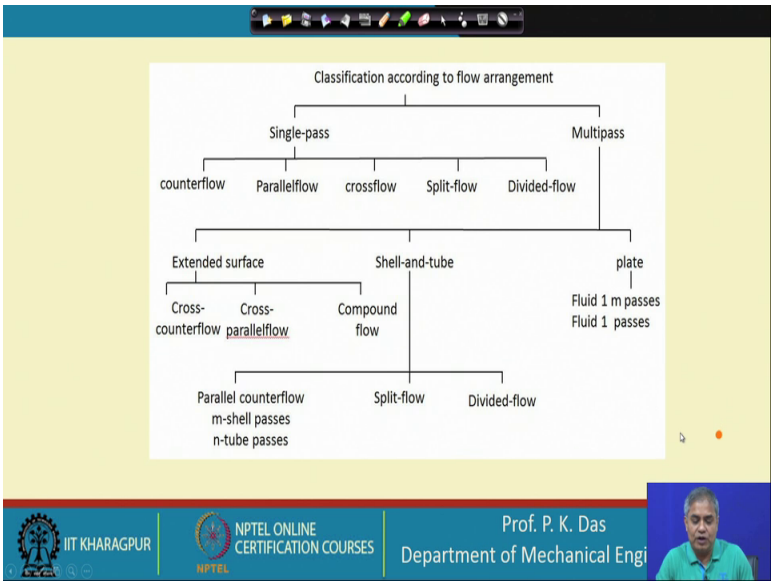
Now, what will happen? Let us see that we are by design we are trying to provide some sort of a mixing, but if there is no mixing what will happen? Let say this is a hot fluid which is coming and this is a cold fluid which is passing over the tubes. So, here when the fluid will come if we go to the next I mean previous slide this idea will be clear, let us go to the previous slide.

So, in the previous slide what we can see? That there is a temperature difference, there is a temperature difference when the fluid is coming out. So, this side fluid is the hot fluid will be cold on this side and hot fluid will not be that cold on this side. So, this difference we can reduce little bit that let us say somewhere in between of the heat exchanger, the hot fluid will be colder this side. So, this cold hot fluid is switched over to the other side and the hotter hot fluid we switched over to the opposite side. If we do that then we can reduce this non uniformity of temperature. So, this is what we would like to do, this is what we would like to do.

So, let us go back to the next slide. So, here what has been done? Here we can see that this fluid when it is coming out fluid 1 when it is coming out, it is sent to the other side of the heat exchanger and from this end fluid 1 is sent to the front end of the heat exchanger. So, this is how we can reduce the temperature variation at the exit of the heat exchanger. And this is actually fluid 1 is totally mixed because there is no passage in between and fluid 2 is partially mixed or unmixed.

So, let us go to the next slide.

(Refer Slide Time: 26:21)

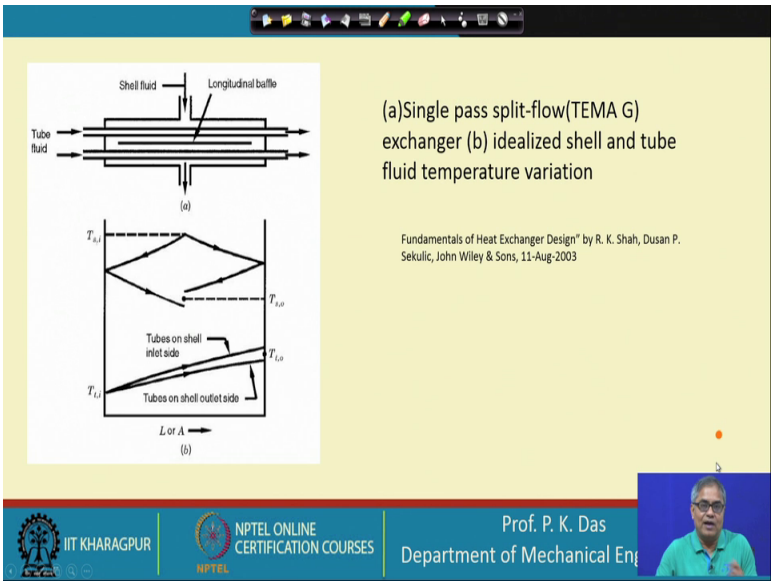


Classification according to the flow arrangement: Flow arrangement we can have single pass. What is the meaning of single pass? If the length of the heat exchanger one fluid covers only once; that is, single pass. If the length of the heat exchanger it covers 2 times, then it is 2 pass and like that. So, single pass we will have counter flow, parallel flow, cross flow, split flow, divided flow like this. So, these are kind of arrangement which are used for in different design and we will see some of them. Then there could be multi plus multi pass and in multi pass shell and tube heat exchanger is one of the example, where we use multi pass.

So, we can have in the shell and tube multi pass shell and tube heat exchanger; parallel counter flow, split flow, divided flow. Then extended surface heat exchanger we can have cross counter flow, cross parallel flow and compound flow; all this thing, I have talked earlier and maybe as we proceed we will see some example.

And then in multi pass we can have plate heat exchanger, then fluid 1 m passes and fluid 1. I mean there could be some number of passes by fluid 1 and fluid 2 by plate heat exchanger. That when we write the I mean read the plate heat exchanger we will try to explain that.

(Refer Slide Time: 28:07)



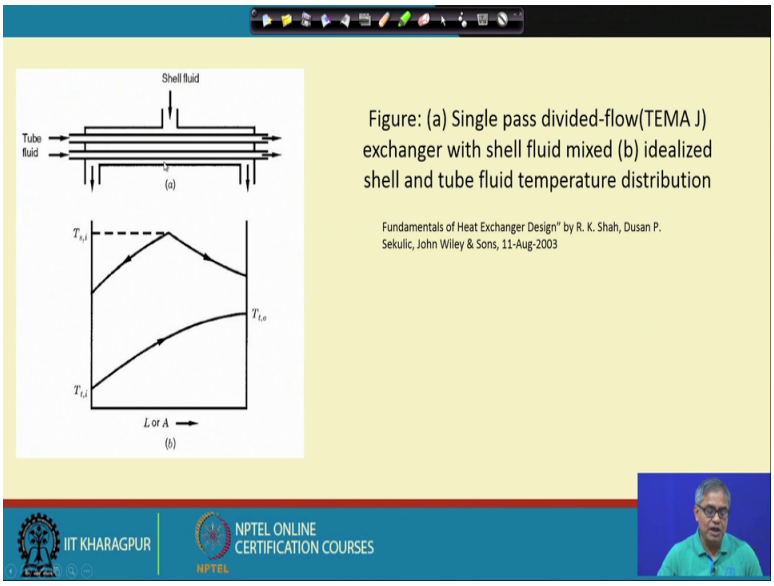
So, I will try to give 2 examples. So, here you see this is basically some sort of a shell and tube type of heat exchanger. In between there is a splitting plate. So, shell side fluid is coming like this. It will get divided and then it will enter here and then again it will get combined and come out, come out where it is coming out there only it will get combined. And then 2 tube side fluid there are 2 tubes and fluid is flowing like this. So, shell side fluid first it is getting divided.

So, one side the temperature variation will be like this, other side the temperature variation will be like this. Then again there is a temperature reduction like this there is a temperature reduction like this and that is how it will come out.

Tube side of course, it will temperature variation will be almost same in both the tubes. So, this is single pass single pass split flow heat exchanger. It has got a special name TEMA G, this point this particular point I draw your attention, this to this word TEMA, TEMA all capital word. So, this is an acronym, this is tubular exchanger manufacture association, this is an association which gives the codes and standard for heat exchanger design, heat exchanger manufacturing, heat exchanger testing, etcetera. So, this is very important who are professional in this field the TEMA handbook is very important and here by defined TEMA one kind of heat exchanger we have shown that is TEMA G, G is the type of the heat exchanger all the description is given here.

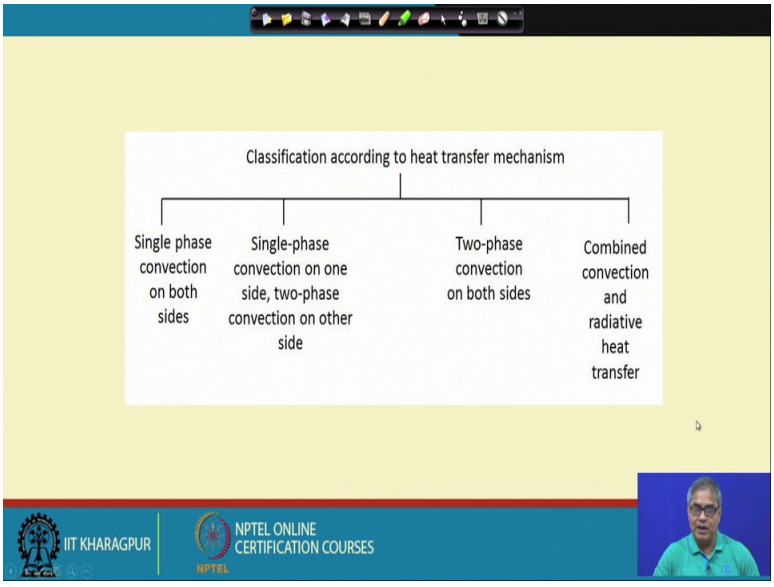
So, let us go to the next slide and let us see another example.

(Refer Slide Time: 30:11)



So, here actually the fluid is coming getting into getting divided into 2 parts and coming out in 2 parts. So, how the shell side fluid will change and how the tube side fluid will change it has been shown, it is self-explanatory again it is TEMA G kind of heat exchanger and we can I mean understand how this is done.

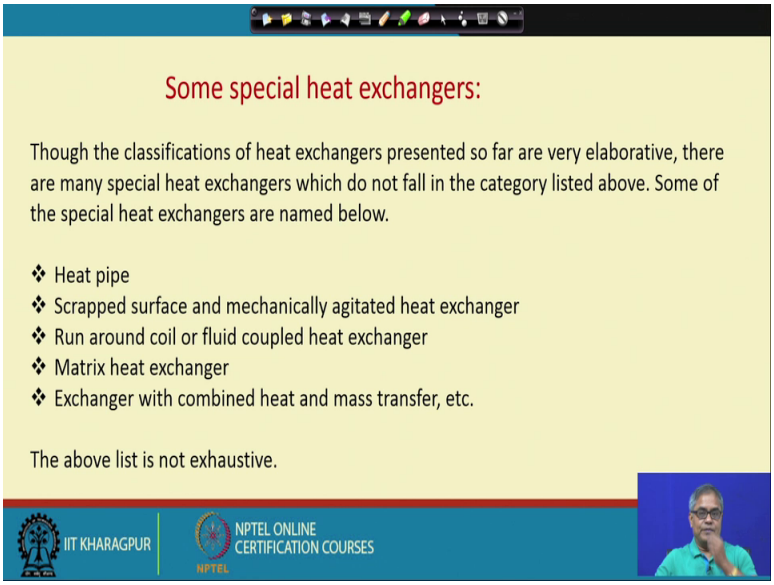
(Refer Slide Time: 30:38)



So, then there could be classification whether it is a single phase fluid then convection could be there on both side. Or it is a 2 phase fluid 1 side there is a phase change or there

could be phase change on both side. Along with conviction there could be radiation. So, this is how we can have some.

(Refer Slide Time: 31:04)



Classification of heat exchanger; lastly with this slide I like to end that whatever we have described that does not cover all the heat exchanger. There are some special heat exchangers and time to time we will describe, what are the special heat exchangers some of the special heat exchangers are heat pipe scrapped surface or mechanically agitated heat exchanger that is used for increasing the rate of heat transfer for very viscous fluid. Run around coil or fluid coupled heat exchanger used for wastage recovery particularly in air conditioning application. Matrix heat exchanger used in cryogenic application then exchanger with combined heat and mass transfer etcetera. Again this list of special heat exchanger is not exhaustive there could be some more special heat exchanger.

So, with this I have tried to give you a glimpse of the heat exchanger family what are the different type of heat exchangers. And more or less we have covered many of them. Unfortunately, some of the description I could not give because of shortage of time and considering that they will be taken up in more details later on, like shell and tube heat exchanger plate fin heat exchanger. We will take up in detail in later course of time, but in the meantime you can see the internet or the reference books to get some idea of this heat exchangers. So.

Thank you.