Energy Conservation and Waste Heat Recovery
Prof. Prasanta Kumar Das
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 30
Heat exchanger (Contd.)

Hello everyone, if you recall we were discussing different kind of heat exchangers and how they can be used for the purpose of waste heat recovery. We have seen 2 very important classes of heat exchanger one is of tubular construction that is either tube in tube heat exchanger or salient tube heat exchanger. Then we have seen heat exchanger with extended surfaces, generally gas side we try to enhance the rate of heat transfer by providing some sort of extra area and that is done using fins.

So, we have discussed or seen fin tube type heat exchanger and plate fin type heat exchanger, both of them are used in suitable applications or suitable situation where waste heat recovery is tried we try to recover some amount of waste heat. So, the salient tube heat exchangers are used in heat exchanger with fins that is used for waste heat recovery purpose.

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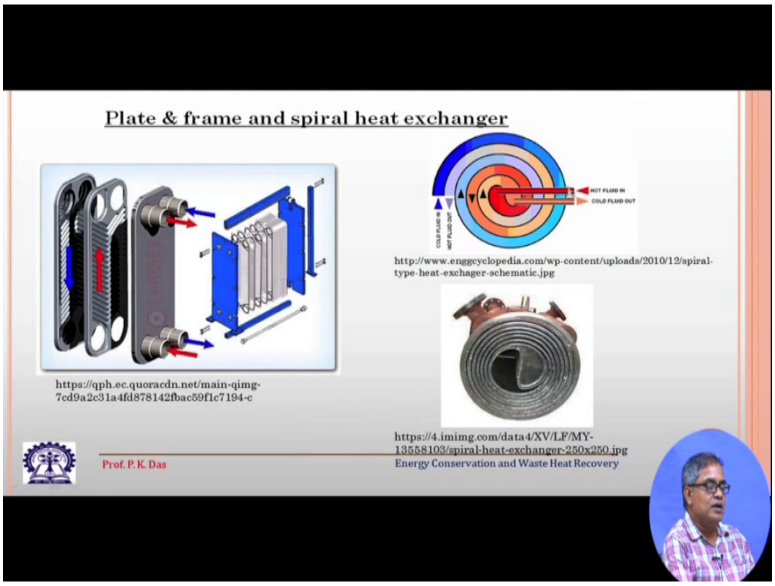

Now, we go to another kind of heat exchanger which has got a very interesting construction, this is plate type in general it is called plate type heat exchanger. The first one if we see on the left hand side this is called a plate and frame heat exchanger and on the right hand side we have got a spiral plate type heat exchanger. Let me explain the spiral plate type heat exchanger so you can see the hot stream is denoted by your, hot stream is denoted by your red color and the cold stream is denoted by your by blue color and then you see the hot stream enters here, at the central location of the heat exchanger it goes through this spiral path and comes out here at the periphery where as cold stream enter over here it goes in and in and comes out somewhere at the center of the heat exchanger. So, the hot stream when it passes at any location you see a hot the hot stream is surrounded by cold stream on 2 sides.

Similarly, a cold stream that will be also surrounded by 2 hot streams; so, this is a very typical arrangement very close contact between the 2 streams and good amount of heat exchange is possible. So, this is one of the devices which can have a potential application in waste heat recovery, because we need compact heat exchanger and we need within a small volume for a given small delta T that is the temperature difference between the heat exchange fluids we want high rate of heat transfer that is possible only when there is close contact between the 2 fluids and the spiral a plate heat exchanger gives one such design.

So, below a physical construction of this spiral plate heat exchanger will be clear from the photograph below, then we go for plate and frame heat exchanger this kind of heat exchangers are more common compared to the spiral plate heat exchanger. In plate and frame heat exchanger there are a number of plates these are thin metallic plates and on this plate these plates are not plain, on this plate there are some sort of surface features and when these 2 plates they come close together these surface features they provide the flow path. So, you can see there could be a jig jag flow path and again by providing this kind of a flow path we can increase the residence time of the fluid.

Then many such plates will be placed one after another sealing will be done with the help of gasket and then they will be tightened in some in some sort of a frame which we will see in an animated film later on and the advantage is that we get a very high rate of heat transfer because of this close contact. Cleaning is very easy because you can open it each and every plate you can clean and then different arrangement of fluid flow can be made and again this is one design of heat exchanger which is very flexible in the sense if we require we can increase the size of the heat exchanger by simply adding more number of plate or we can reduce the size of the heat exchanger.

So, this is a very unique design there are certain limitations like these heat exchangers cannot withstand very high pressure because there could be leakage from the gaskets or very high temperature also it cannot withstand and it suitable for handling cleaner fluid because the passages are very small it can get clogged by dot, dot etcetera if the fluid carries that. So, apart from this, this is a very good arrangement for intense heat transfer between 2 streams suitable for waste heat recovery purposes where heat is to be extracted from a hot fluid by another fluid particularly when there is power generation. So, we can use this, for renewable energy also there is lot of use for this plate type heat exchanger; that means, let us say we want to extract power from the geothermal energy source of energy.

So, the hot liquid can be circulated through one side and the working fluid of this suitable cycle that can pass through the other side other side of the plate and we can get a good amount of heat exchange.

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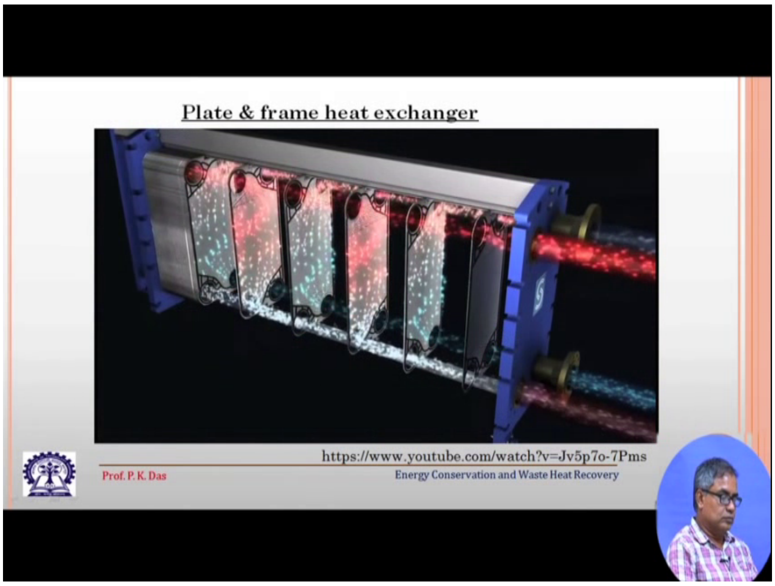

Let us now go to some sort of a animated.

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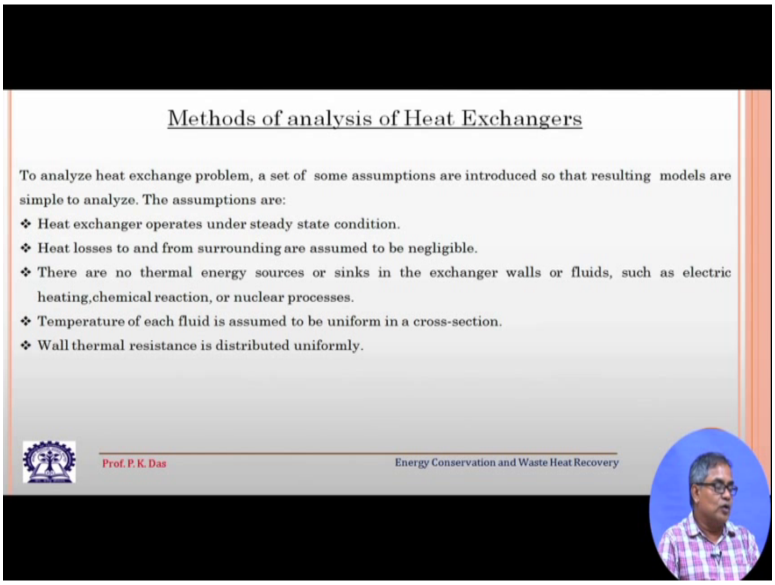

So, now we go for method of analysis of heat exchanger, now this is this could be quite elaborate we will not go into any derivation, but the salient features and the methods of the analysis of heat exchanger we will just touch cursorily. So, that it can act as some sort of for re capitulation of whatever many of you have learned regarding heat exchanger and we know certain important formally so that some calculation basic calculation can be done.

Now, this is done based on based on certain assumptions, heat exchanger operates under steady state condition and heat losses to and from the surrounding is assumed to be negligible heat exchanger is assumed that it is insulated and if any heat exchanges their thermal energy exchange is there that is between the 2 fluids. Then there are no thermal energy source or sink within the heat exchanger and temperature of each fluid is assumed to be uniform in a cross section velocity is also assumed to be uniform in a cross section then wall thermal resistance is distribute distributed uniformly.

Now, with this assumption there are many methods of analyzing heat exchanger, 2 methods which are very extensively used one is called LMTD or s lmpd method and another is effectiveness ntu method. Both this method we will just touch upon very briefly highlighting the formula which we have form the relationship which we get and then probably with some example we will see how small calculations can be done.

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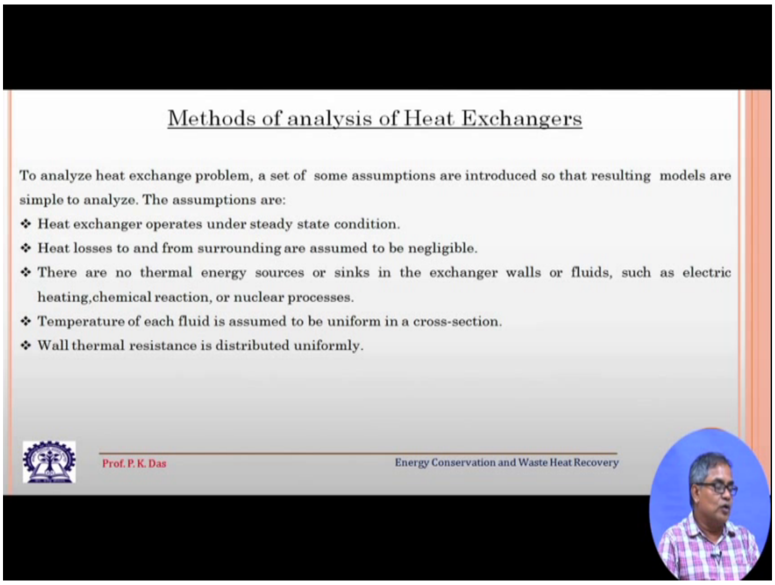

The definition what we get that is like this the one thing is very important we have to know what is the heat transfer resistance or in other words which is reverse of resistance what is the overall heat transfer coefficient when heat is being transferred from one fluid to another fluid. Now, generally we assume the overall heat transfer coefficient to remain constant along the length of the heat exchanger, at least we will take examples or we will our discussion will be limited to those kind of applications where we can consider the overall heat transfer coefficient to be a constant over the length.

Then what we can get this is the basic equation of heat transfer dq d elemental heat transfer that is equal to u into temperature of the hot fluid th minus T c temperature of the cold fluid that is locally this is the temperature difference multiplied by d a the small amount of area which is responsible for heat transfer. So, we get this one, U into delta T into da the above equation can be presented in an integral form and this is what we will get where u is the capital u that is the overall heat transfer coefficient.

Now, the definition of mean temperature difference and mean overall heat transfer coefficient is as follows, delta T mean that is the mean temperature difference one has to remember or one has to appreciate one thing the local temperature difference between the 2 strains which is the driving force for heat transfer it changes along the length of the heat exchanger, in general it will change along the length of the heat exchanger.

So, we have to have some sort of mean temperature difference and that determination of the mean temperature difference that becomes the crux of the point in the analysis of heat exchanger. So, we get this kind of a relationship and from there you aim that is the mean overall heat transfer coefficient is given by this relationship and q that is given by U m into a into delta t m. Here is the mean overall heat transfer coefficient delta tm is the true mean temperature difference, mean temperature difference that is called MTD also referred to as mean temperature driving potential or force for heat transfer that is what I told that the difference of temperature between the hot stream and the cold stream that is the driving force or driving cause for heat transfer to take place.

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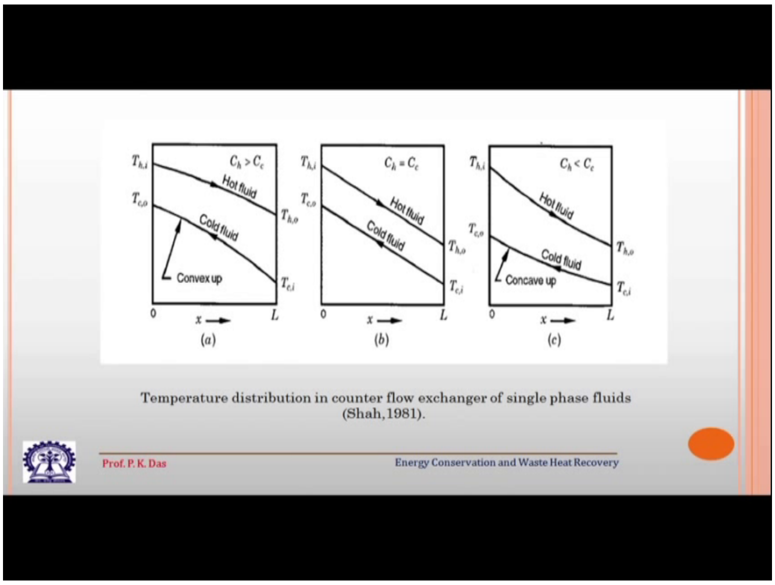

Now, at this point I like to show or like to discuss 3 arrangements which are very important as far as our analysis is concerned, 3 arrangement of fluid flow which are basic arrangement of fluid flow.

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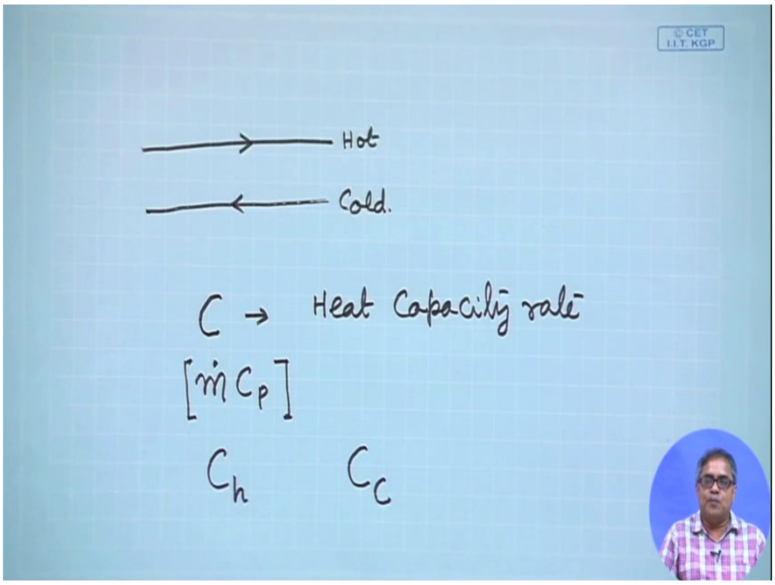

So, now, if we if we see the first arrangement, let us say this is one fluid and the other fluid is flowing in the opposite direction, let us say this is hot and this is cold. So, what we will have the arrangement is called a counter flow arrangement. So, the fluid flow directions are opposite to each other. So, if we go back to the ppt then we will find that temperature distribution in counter flow heat exchanger of single phase fluid, this is from the book this figure has been taken from the book of R K Shah. And the hot fluid it will enter at th i and go out at th o its temperature will fall and then the cold fluid entered at tci and it goes out at tco its temperature will increase, this is for a case when Ch is greater than cc.

So, c this is a quantity which needs to be which needs to be defined C is called heat capacity rate, what is heat capacity rate? It is m dot mass flow rate multiplied by C p. So, this is your heat capacity rate and this heat capacity rate we m dot of course, remains constant because at the beginning we have told that we are dealing with steady state situation. So, for a particular, for a particular stream m dot remains constant and C p we assumed to be constant it does not change with temperature. So, that it does not change along the length of the heat exchanger. So, m dot C p is called the heat capacity rate and when we are denoting it by C h. So, this is heat capacity rate of the hot fluid and when we are denoting it with the subscript C it is the heat capacity rate of the cold fluid C c, C h and C c. So, these 2 things are very important parameters in our heat exchanger analysis.

Now, again let us go back to the ppt. So, first case is Cc, C h is greater than cc in the second case C h is equal to C c, then the temperature change of any of the fluid stream will be linear along the length of the along the length of the heat exchanger and the second the third case that is C h is greater than Cc, we will have this kind of heat temperature change of the fluid stream. So, this is for parallel, this is for counter current flow.

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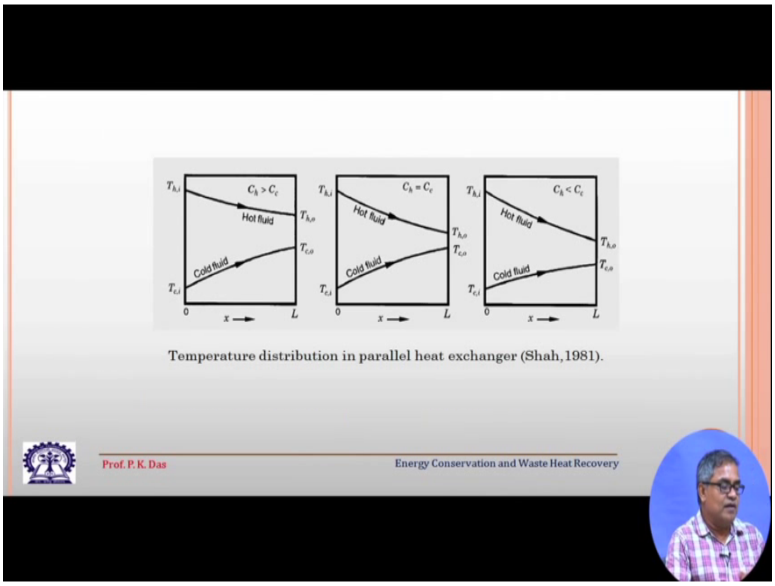

Next if we go this is for parallel flow.

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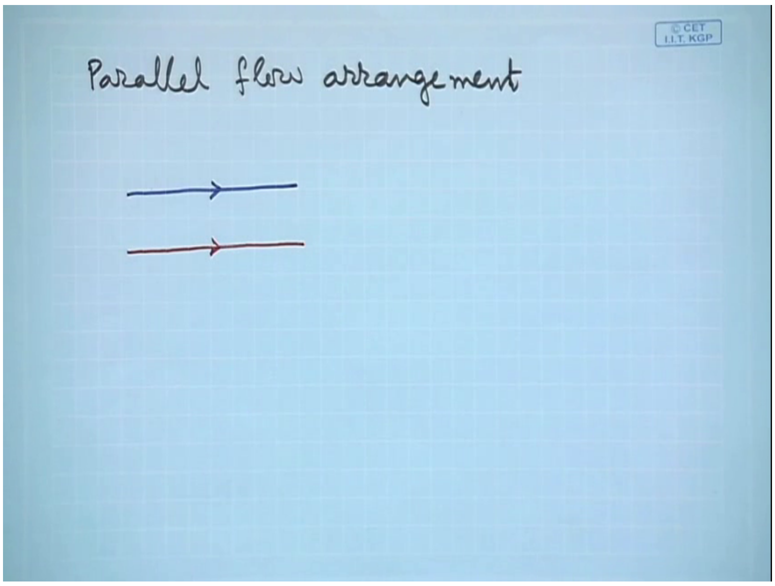

So, in parallel flow parallel flow arrangement. So, so let us say the cold fluid is flowing like this, the hot fluid that is also flowing in the same direction. So, this is your parallel flow, now in parallel flow arrangement both the fluid enters at the same end of the heat exchanger and it goes is that goes out at the other end of the heat exchanger. If we go back to the ppt we will find that here the both the hot fluid and cold fluid enters, this is the one end of the heat exchanger and this is another end of the heat exchanger here both the hot fluid and cold fluid they are coming out, but the cold fluids temperature has increased whereas, the hot fluid temperature that has decreased.

So, what we get to start with; we will have a very large temperature difference between the hot stream and the cold stream, as we proceed towards the exit end of the heat exchanger this temperature difference reduces and it becomes the minimum at the exit end of the heat exchanger.

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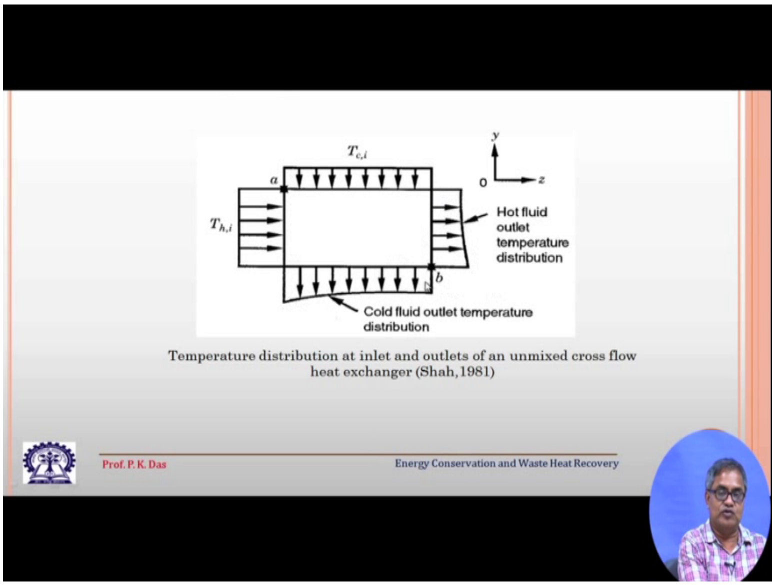

So, this is your parallel flow heat exchanger and the third type of heat exchanger is called the cross flow heat exchanger. So, in the cross flow heat exchanger the direction of flow of the 2 fluids are perpendicular to each other, let us say the hot fluid enters here and the cold fluid enters here, this is where the hot fluid comes out the temperature distribution will be something like this. And this is where the cold fluid comes out its temperature distribution will be something like this and here you see though at the inlet the temperature distribution of the 2 fluids are uniform, when it comes out at the other end of the heat exchanger the temperature distributions are not uniform. The reasons are obvious you can you yourself can analyze and see that is what it has to happen.

Now, the when we talk about the exit temperature we talk about the mean temperature at the exit either for the hot stream or for the cold stream. Then there is another variation when there is a cross flow all the fluid streams let us say there are fluid streams and the fluid is passing through the through some sort of a tube there are a number of tubes. So, the fluid is unmixed. So, the fluid can be unmixed or if the fluid in a particular stream can mix also when it passes through the cross flow heat exchanger. So, these 2 variations are there.

So, these 3 type of heat exchanger which I have described they are the basic type of heat exchangers or rather they are the basic flow arrangement in heat exchanger, in many heat exchanger we will find that there are combination of these 3 basic direction of flow. So, that is one thing we have to keep it in mind that in many heat exchanger we will find a combination of these 3 type of heat exchanger. Now, the analysis is done assuming that either we have got parallel flow heat exchanger or we have got counter current flow heat exchanger. So, basic analysis can be done from there and we will start from there and see how this analysis is done.

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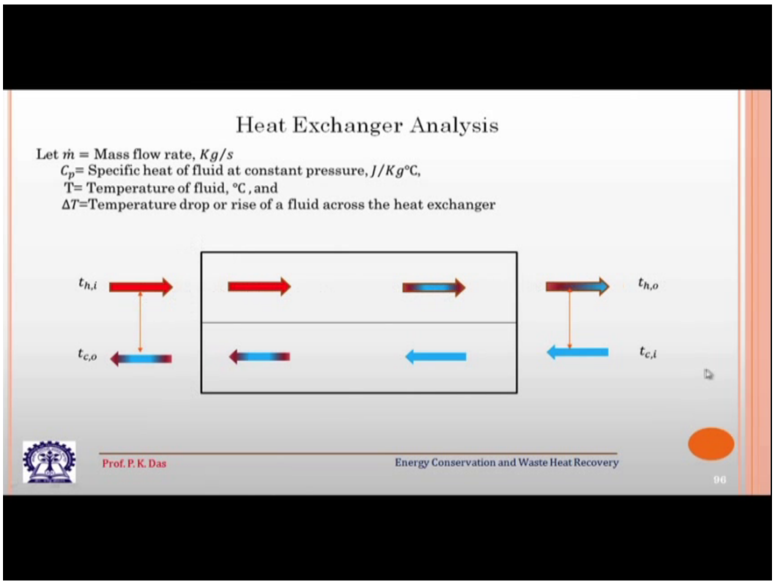

So, you see heat exchanger analysis if we go, here I am showing a parallel flow type of arrangement hot fluid is passing and as it passes its temperature reduces it goes out, the cold fluid enters from the other side as it passes its temperature increases and it comes out with a with the lowest temperature.

So, these quantities are important that m dot that is the mass flow rate kg per second that remains constant, C p specific heat of fluid at constant pressure. So, this is the unit joule per kg degree Celsius that also remains constant for our for the purpose of our analysis. In some cases due to temperature there could be variation of C p, but the analysis which I will show that cannot catered to that kind of change in C p. T temperature of the fluid degree Celsius and delta T is the temperature drop or rise of a fluid across the heat exchanger ; that means, the hot fluid is entering at th i it is going out at th o, th i minus th o that could be delta t h; that means, it temperature drop for the hot fluid. Similarly tco minus tci that is delta tc that could be the temperature rise for the cold stream, there is some other definition of our rather some other use of delta T suppose this, this end of the heat exchanger we denote it by 1. So, thi minus tc o that could be delta t one that could be denoted by delta T 1.

Similarly, the other end here the temperature difference is th o minus tc I this could be delta T 2, if we take this exit end as 2. So, these are different symbols or notations which we use for heat exchanger analysis.

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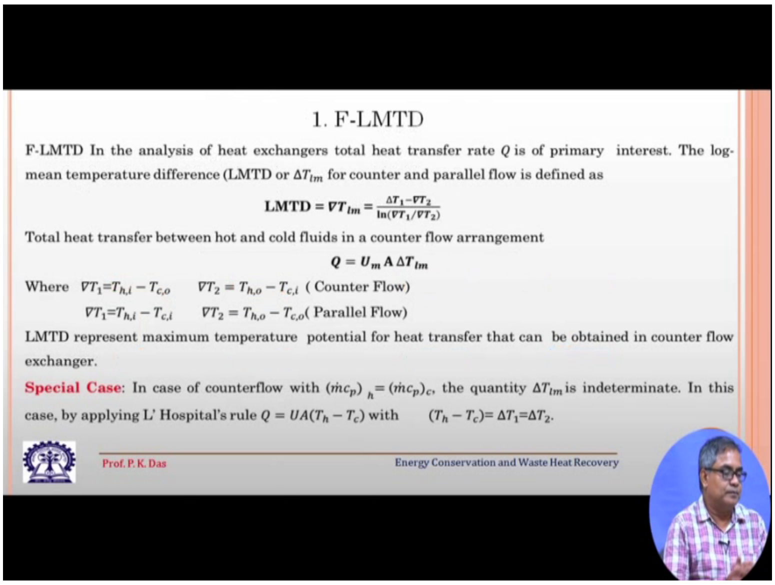

Next first we like to see the F LMTD method, F LMTD method this is one of the very well known, well used method for heat exchanger analysis the by some sort of simple analysis based on the assumptions we have made the mean temperature difference for the heat exchangers. Either for either it is parallel flow or it is counter flow we can get the mean temperature difference as LMTD which is delta T 1 minus delta T 2 divided by log of delta T 1 by delta T 2.

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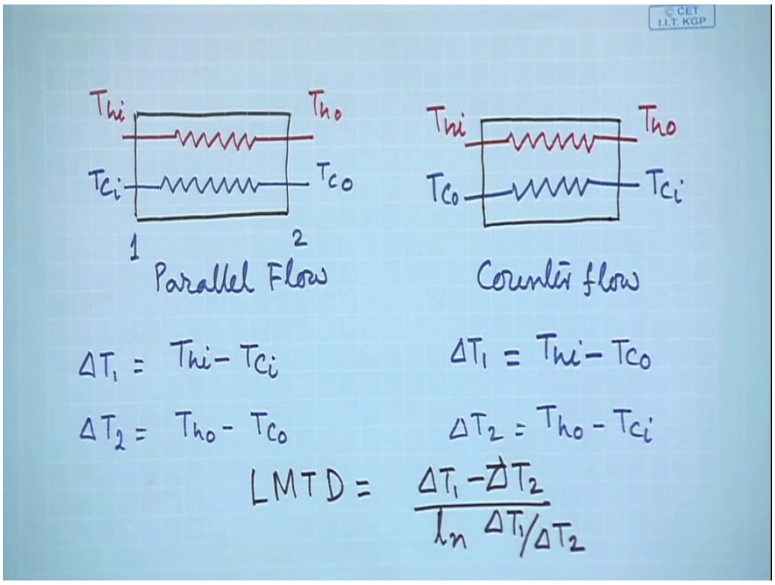

So, this needs certain explanation of course, many of you are familiar with it. So, please bear with me for those who are not familiar with it. So, let us say these are 2 arrangement this is T hi, T ho and then there is T ci, T co. So, this is parallel flow. So, this side is end 1, this side is end 2 and delta T 1 is equal to T hi minus T ci delta T 2 is equal to T ho minus T co, or we can have the hot stream T hi, T ho and the cold stream T ci, T co . So, this is counter flow, delta T 1 is equal to let us say T hi minus T co delta T 2 is equal to T ho minus T ci.

So, with these things we will have what? We will have the lm td is equal to. So, let me write this, let me write this for your benefit LMTD is equal to delta T 1 minus delta T 2 divided by ln of delta T 1 by delta T 2. So, with this let me stop for the time being we will again restart from here and we will see how we can do the analysis of heat exchanger.

Thank you.