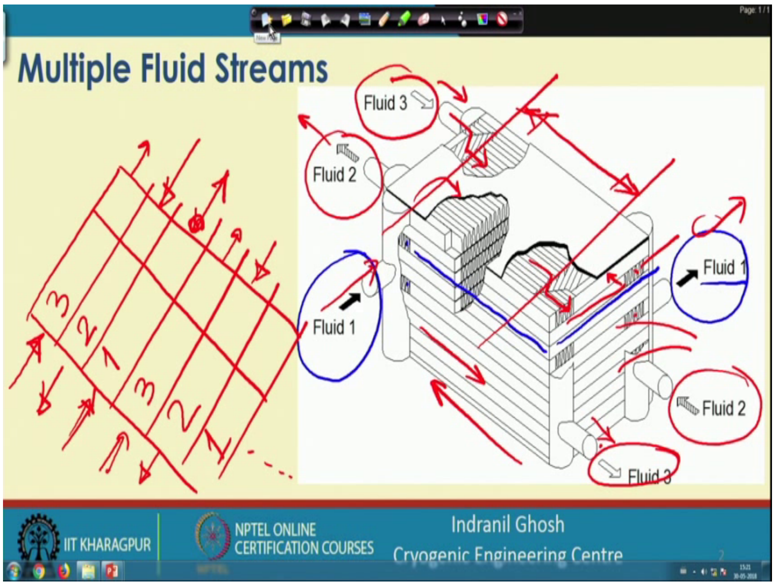
Heat Exchangers: Fundamentals and Design Analysis
Prof. Indranil Ghosh
Department of Mechanical Engineering
Indian Institution of Technology, Kharagpur

Lecture- 32
Plate fin heat exchanger: Multistream

Welcome to this lecture. We are going to talk about Plate fin type heat exchanger where it will be handling multiple streams, multiple fluid streams. So, this while talking about the plate fin heat exchanger characteristics, we have told you that one of the characteristic feature of the plate fin type heat exchangers is that, it can handle multiple fluid streams in single unit and that we take it as an advantage because several fluid, fluid streams in a single unit can often offer high degree of compactness and also, thermal performance enhancement in the thermal performance. So, if we look at the plate fin type of heat exchanger geometry to accommodate multiple fluid stream in a single unit how it has to be done.

(Refer Slide Time: 01:17)



So far we have talked about the two fluid stream geometry just if we enhance another fluid stream for ease of understanding, we have here shown only 3 fluid stream. So, here one of the fluid stream is fluid number 1, fluid 1. So, it is entering at this layer. So, at this side and it is moving out from this side. So, as you can understand that this is the fluid stream entering from this opening, this opening and so, many others you know feature in this layer, particular layer. It will be coming out from this end and finally, it will move out from this side.

Now, what is about the other fluid streams say fluid stream 2? This is entering from this end and you can understand that this is in layer 2. So, it will be coming in from this side, this side and this side. So, here this layer is designated for fluid stream 2. This is for fluid stream 2; this is fluid stream 2 like that and they are all coming out you know on this side.

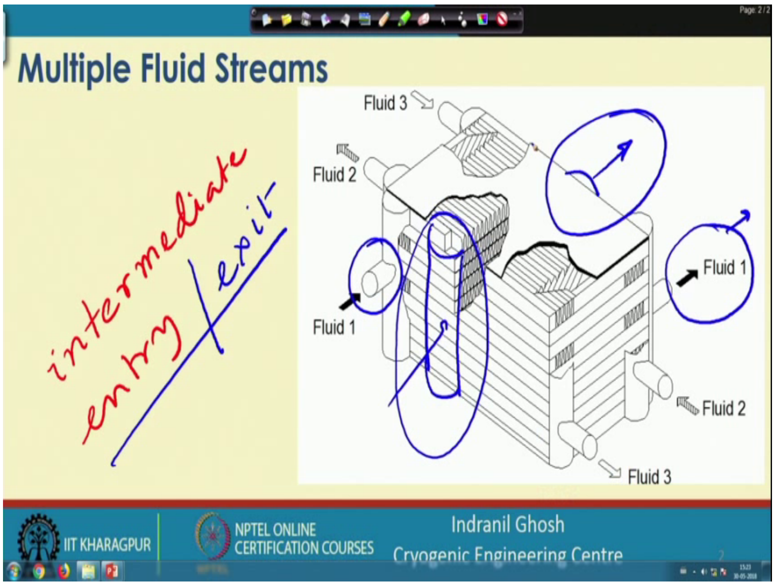
So, what is about the third one, the 3rd fluid stream? So, it is entering from this side and coming in. So, this is occupying the first layer and then, moving out from this side and finally, it is going out from this side. So, like that the arrangement is 3 2 1 and there is repetition of this again 3 2 1 and so on. So, it is like that it will be arranged. So, if we look at the geometry, particular geometry of the heat exchanger and if we restrict ourself from this length to this length, we find that these 3 fluid streams are you know this is the fluid stream 3 is entering from this side and this is moving out from this side, where as very next fluid, fluid 2 which is entering from this side and moving out from this side, so they are in countercurrent configuration.

So, if this fluid 3 is entering from this end and fluid 2 is entering from this end, so their countercurrent configuration within this span of exchanger what is about the fluid stream 1. Now, here fluid stream 1, we find that it is though it is we know as it looks like cross-flow arrangement, but immediately after going inside, it will take a turn and finally it move out from this side. What is about fluid 2? In contrast of fluid, the 2, the fluid 2 is moving from this end to that end, the fluid number 1 is entering from this end to this side and that means, this is also in countercurrent to this.

So, we can see that this fluid streams 1 to 3 are in countercurrent configuration with each other. So, again you know the 3 will be coming here and 3 will come from this side. It will come out from this end and 2 will be coming from this end to this end and so on. So, all this stream, fluid streams are in countercurrent arrangement to each other whereas, it will be overall it may look though you know countercurrent and cross flow arrangement, but internally within this length they are in countercurrent configuration.

So, this one of the beauty of this plate fin type heat exchanger where it can handle multiple fluid streams and not only that, this fluid stream can be or I mean as many as 11 number in I mean we have come across heat exchangers handling 11 number of fluid streams and another particular feature of is of this particular type of heat exchanger is that we may take out the fluid at some intermediate points.

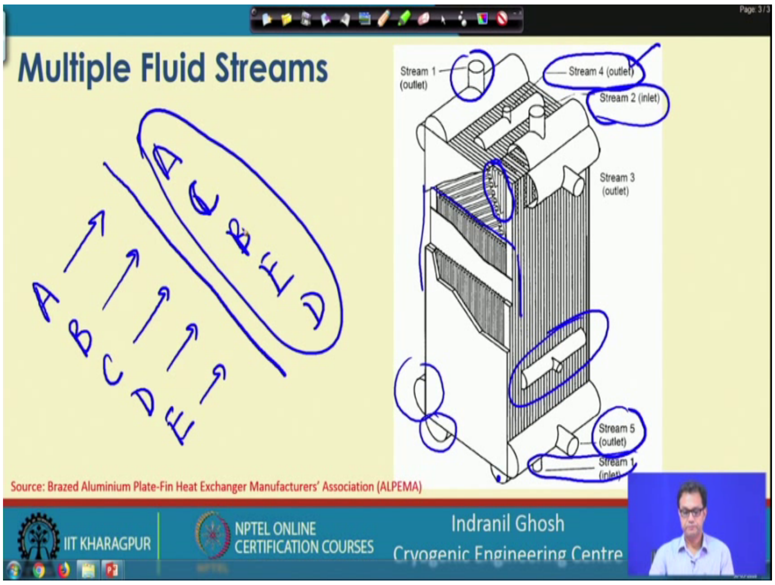
(Refer Slide Time: 06:11)



That means intermediate entry and intermediate exit is also possible. Intermediate entry of the fluid stream and intermediate exit of the fluid stream, intermediate exit of the fluid stream is possible. That means, it did not necessarily enter from this end and come out from this end. I mean travel all the way to this heat exchanger length and come out from this end. If someone wants you know it may be taken out from this point also and it may so happen depending on the heat exchanger length.

We may think of entering the fluid stream from this end. So, this becomes intermediate entry and this becomes intermediate exit and that is possible for any fluid streams. So, this intermediate entry and exit of this multiple fluid stream is again another characteristic features of the plate fin heat exchanger. So, with this basic knowledge of the fluid streams, now we go to the next I mean picture where we can see some of the plate fin type heat exchanger.

(Refer Slide Time: 07:33)



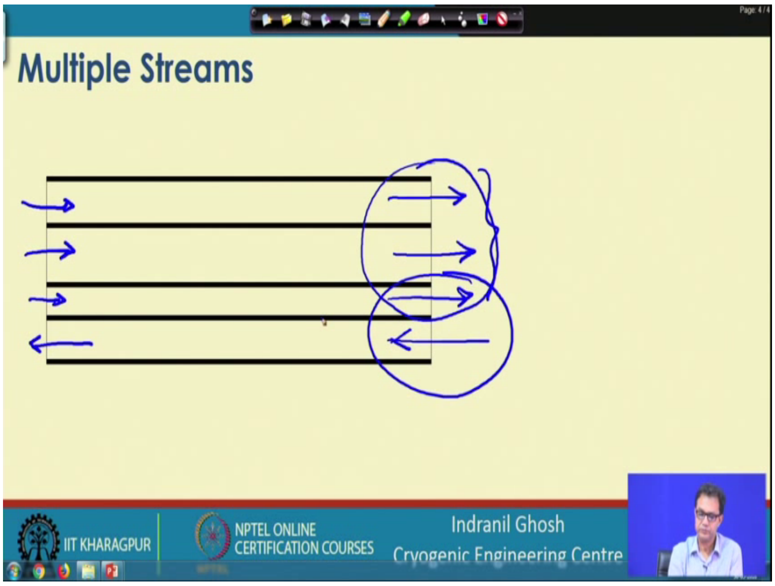
This has been taken from the ALPEMA, sorry heat exchanger and here we find that this is the particular exchanger is showing as many as 5 fluid streams and many of them are you know entering this particularly is entering from this end. So, this is one end and here you may find that this is something where you know this is there is an intermediate entry or exit and this is the fluid stream 4 outlet fluid stream 2 outlet. Sorry this is stream 2 inlet and this is where the fluid 4 is moving out stream 1. This is stream 5 outlet and it is not shown the entry, showing the entry of other streams. So, the switch must be located on this side or this side. So, this is the topical type of plate fin type of heat exchanger and you can understand that it should have very good type of distributor fin before it comes to the main length of the exchanger.

So, in this type of exchangers, it is the parallel counter as well as cross flow arrangement is likely between the fluid streams. So, it will depend on the optimum fluid you know pattern we will talk about that. As you can understand that when we have say A B C fluids or A B C D E number of fluid streams, then how do you arrange them that also you know makes some kind of possible configuration like whether we should go for A C D E D like that this combination or we will arrange them in a different combination and how this pattern will, the layer stacking pattern we will discuss about that part sometime later.

So, when we talk about this kind of plate fin type of exchangers, now imagine that the configuration of the heat exchanger is already known or it is basically we are not going to talk about the design at this moment. We are going to talk about the simulation process of heat exchanger or multistream plate fin heat exchanger. That means, we know about the total dimensions or the configuration of the heat exchanger and we know the inlet fluid stream conditions, so that we have to I mean find out the performance of this plate fin type heat exchangers or we will try to find out what are the exit fluid streams temperature and the pressure.

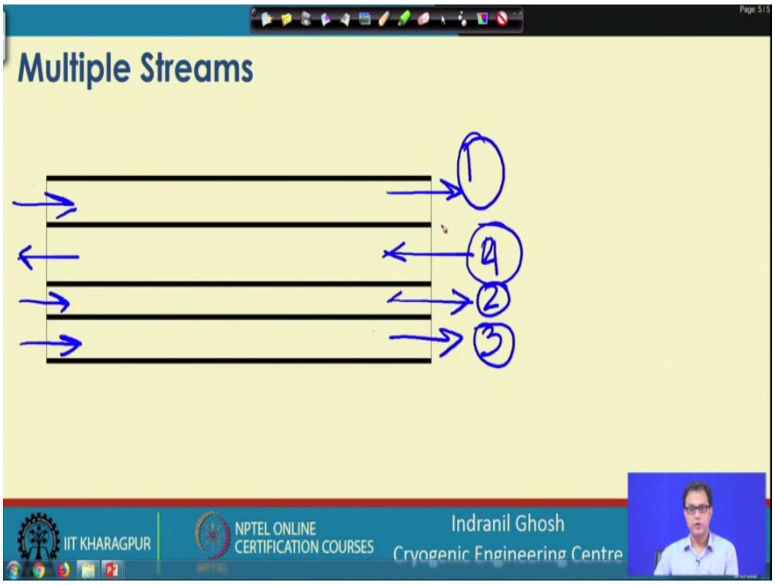
So, how to do that? We will try to understand that one and the associated problem with this particular type of heat exchangers. So, we will look into that.

(Refer Slide Time: 10:50)



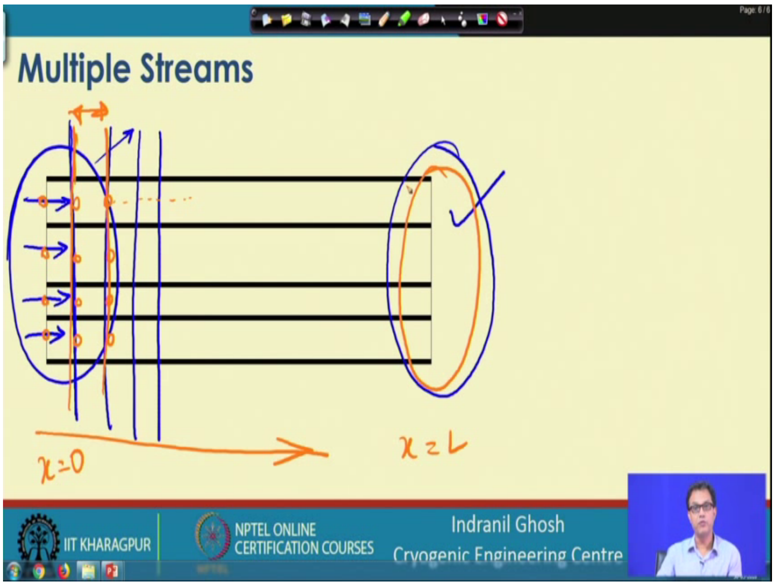
So, now imagine that this particular example we will be showing you to demonstrate why this design or simulation particularly is complicated in case of plate fin type heat exchanger. Imagine that we have fluid stream which is all the fluid streams are entering from say this end to this end. I mean they are entering from this side and moving out from other side except one fluid stream, but let us this is where we have these 3 fluid streams, their imperial combination to each other, but these 2 fluid streams are in countercurrent configuration or it may be of different configuration also.

(Refer Slide Time: 11:50)



It may so happen that the fluid stream 1 is entering from this side say another fluid stream that 4th, I mean earlier which was there at this location, now we have this on this side and this is the other. So, this is fluid stream 1, this is 2, sorry this was 4, right. This is 2 and 3. So, 1 2 3 are entering from this end and other one is entering from this end. So, one of them is in countercurrent to other. So, this is one combination.

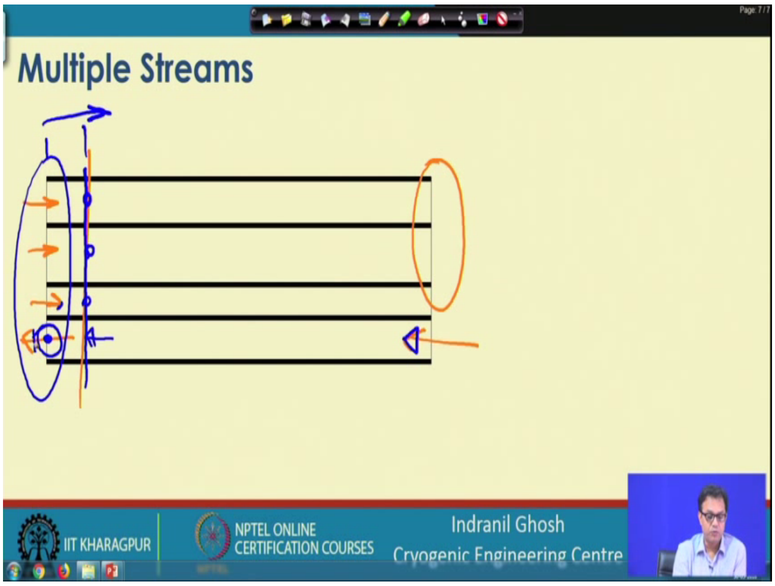
(Refer Slide Time: 12:31)



It could have been such that all four of them or I mean all the 4 fluid streams are entering from one end. So, simulation of this particular type I mean is bit easier as compared to the other situations we have talked so far. So, here all the fluid streams are entering from one end and we need to find out exit temperature or the exit pressure at this end, where it is not known and what we do is that we go step by step if we divide this enter exchanger into small piece and what we try is, if it is divided into a very small piece and we can try to find out the exit temperature at this point.

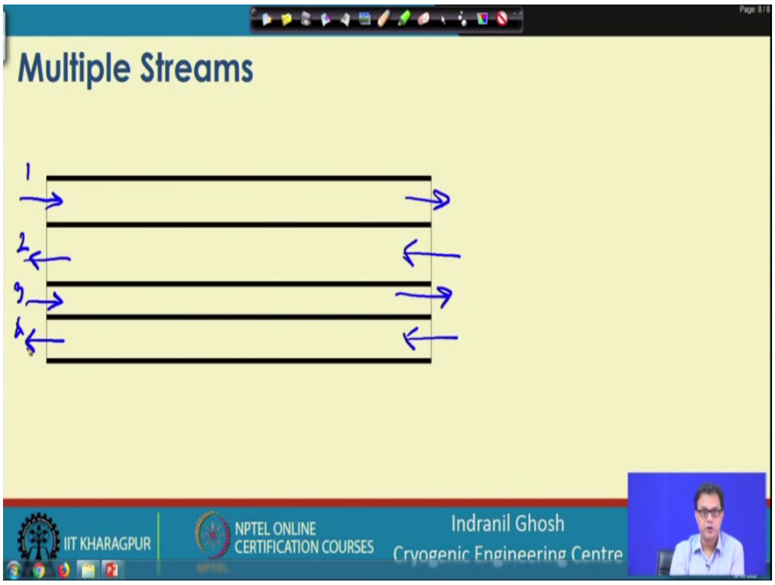
So, we know all this temperature at this end it is known at this face and we can try to find out the temperature at this location. So, if we find out the temperature at this location, so if we can find out the temperature at this location, it will act as an input for the next session and we will be able to calculate the exit temperature for this tiny you know length of exchanger. So, it will keep on integrating from this length to this direction I mean from x equals to 0 and x equal to 1 and we would able to finally get an exit temperature at this end. So, that is what is the process when all the fluid streams are entering from one end and moving out to the other side.

(Refer Slide Time: 14:19)



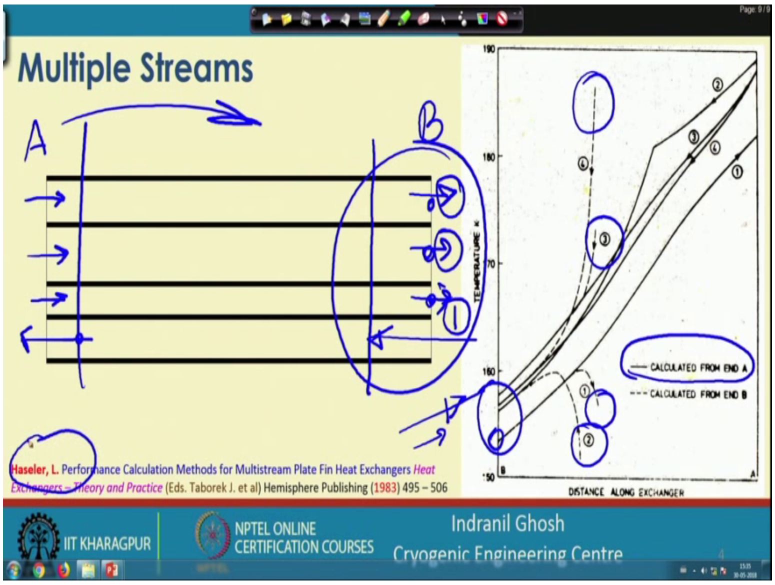
So, all the fluid streams are in parallel combination to each other, but if the situation is not that if 3 of them are entering from one side at least and one of them is you know coming from other side, so if this the situation, then what happens. So, we can make an estimate of say these 3 because here at this point if we have to make a small section of this exchanger, what we need may be you will starting from this end and where this all these 3 fluid streams are temperature, I mean fluid temperatures are known. So, we have it is convenient to start from this end if we just assume only one fluid temperature for this one. So, we should have been I mean we should be ideally able to predicate the outlet temperature for these 3 fluid streams and then, you know one fluid stream on this side. So, what is the problem if we have this kind of situation, this can also be I mean handled if we write the governing heat transfer and pressure of equations and then, we try to solve it step by step or from this end to this end just step by making an assumption for a single fluid stream I mean.

(Refer Slide Time: 16:06)



So far as the assumption is associated with single fluid stream, we have no problem, but if it is such that if we have to if the configuration such that, we have more than one fluid stream entering from both the ends I mean this is like we have a countercurrent fluid stream arrangement where alternative hot and cold fluid is there like you know this is fluid stream 1, this is fluid stream 2, fluid stream 3 and fluid stream 4. This is 1 and 2 are in countercurrent, 2 and 3 are again in countercurrent arrangement as well as 3 and 4 are again you know flowing countercurrent to counter in countercurrent arrangement.

(Refer Slide Time: 16:50)



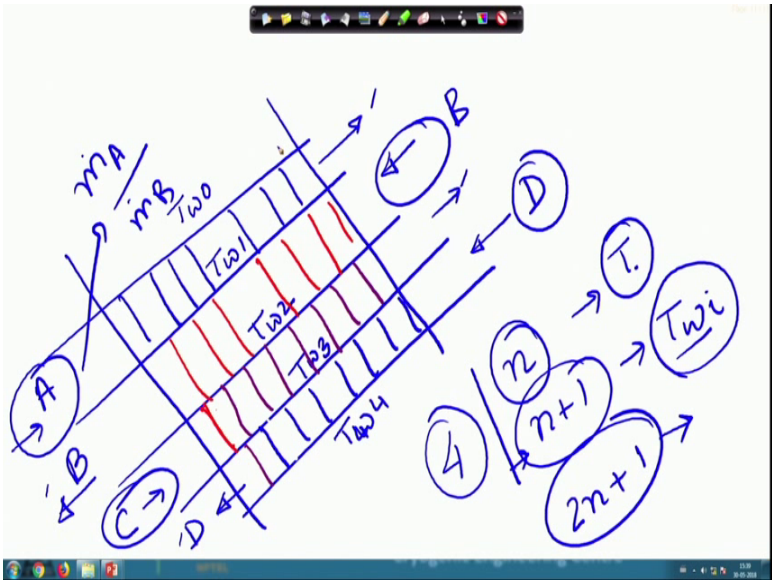
So, now in this configuration what happens is that this is this has been shown by Haseler in her paper performance calculation methods for multistream plate fin type heat exchangers. Here what he has shown that when I mean this is a configuration where we have like, let us look into that carefully. So, when this is calculated from end A, that means as we were telling you that we have 3 fluid streams here, you see 2 3 4. They are entering from one end and then it has been designated as A and other end as designated as B and from B end which is the fluid flowing, this is the fluid number 1 that is flowing from end B to end A.

So, this is end A, this is fluid stream number 1. So, now when they have calculation I mean started from end A, that means they have made an assumption about this exit temperature and they have approached to the solution from end A to end B and then they are finding convergence of this outlet, I mean fluid temperatures, but look at the situations. When they have started from the end B, end B means what are the thing that he has to I mean she has to do with that.

Tese are coming like this. So, if we have to simulate from this end, so one has to assume the fluid temperatures at these 3 points. So, even if someone is very close to the actual exit temperatures and if someone try to you know start simulation from end B, it will be such that it will be very soon I mean it will diverge, the solution will diverge. So, we are not going to get any kind of solution when we are going to make a very you know even if we make very close you know assumption to the exit temperature also. It is not going to converge.

So, in order to solve this problem I mean this iterative scheme is not going to help much. So, we need to add a different type of scheme for the multiple fluid stream heat exchangers and there are several works and one of them is of course by Haseler. I mean haseler and there are other papers or I mean literatures available in this end in different channels and book. So, we will look into that I mean how do we go on about it. So, we will try to first solve, we will go to the, if we now look that we have a different fluid streams like this say A B C D.

(Refer Slide Time: 20:07)



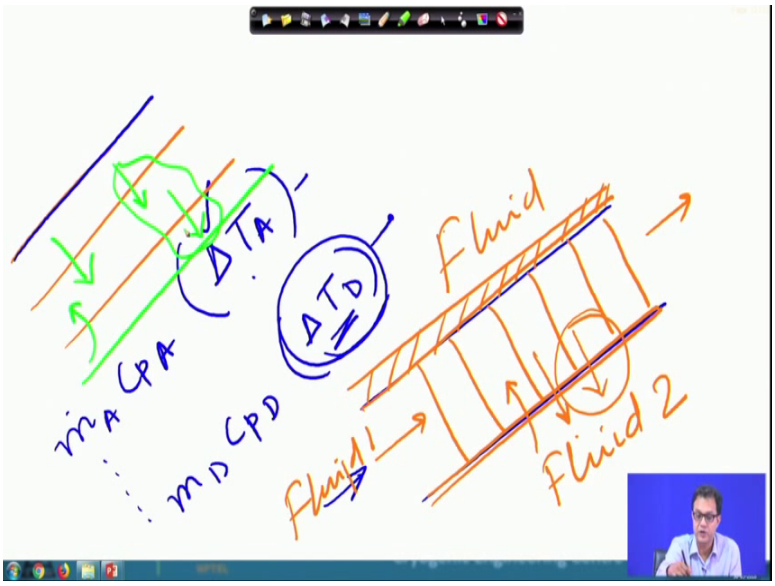
This is fluid stream A, then fluid stream B and C and D and they are arranged in either parallel or countercurrent combination. So, first of all what we need to find out is how is the governing heat transfer equations and then, only we will be able to find out the solution of the governing heat transfer equations. So, now what we need to solve these equations, what we have with us is the heat exchanger geometry known to us and what is known is the indebt temperature of all these fluid steams.

This is fluid stream B, this is fluid stream C inlet is known and this is fluid stream D inlet is known. All the inlet temperature and the heat exchanger configuration is known to us. Now, based on this we should be able to find out the exit temperature of all these fluid streams A B C D exit temperatures. So, if there are 4 fluid streams, we need 4 exit temperature, then what are other things that are not known are the world temperatures say T w0. If we designate it, then you know T w1 T w2 T w3, all this word temperature also you know it matters. So, we have then n number of fluids, then we have you know n plus 1 number of word temperature are known to us. So, we n number of fluid streams and their exit temperature are not known and we do not have information about the word temperature for n plus 1 number of separating plates. So, all together what we expect that 2 n plus 1 number of unknowns we look for the solution of that 2 n plus 1 number of unknowns.

Now, if we have to look for 2 n plus 1 number of unknowns, we need 2 n plus 2 n plus 1 number of equations. So, we have to construct equations for 2 n plus 1 number of this. Now, as you can understand that if you make cross I mean cross-section of this plate fin type exchangers, we will find that there are fins in between the two layers and it will be looking like this. So, what we will try to do is that we will try to solve I mean what we need, what will need is basically kind of energy balance for all the fluid streams and particularly the fluid streams I mean all the fluid world temperatures.

So, it is all the fluid streams, but we can write is that we also known the mass flow rate for the individual streams. So, m A dot m B dot like that all the mass flow rate of the fluid streams are also known to us. So, if we assume that for this equations we should be able to write in terms of m dot A C PA.

(Refer Slide Time: 23:55)



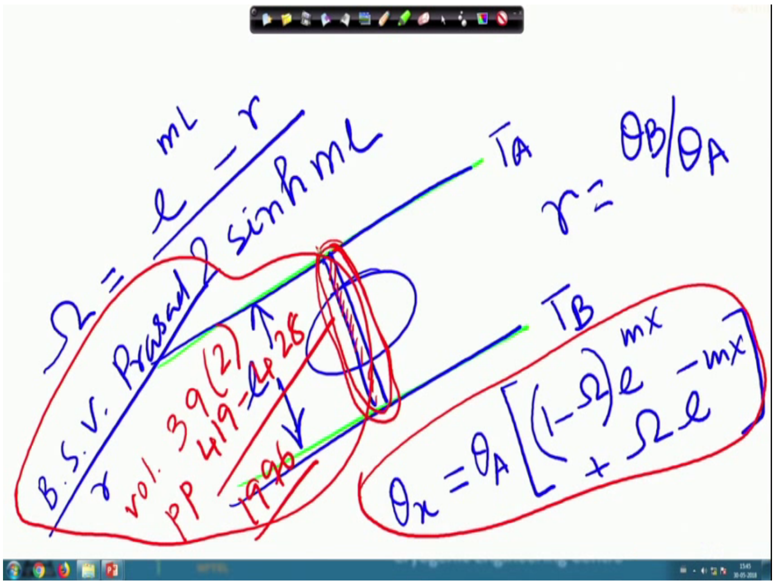
Then, you know delta T A, where one of the temperature is known, the inlet temperature is known, but the exit temperature is not known. Similarly we would be able to write you know CPD and then, we have the delta T and delta T D and there also we find that one of the temperature is known in delta T inlet temperature is known, but the exit temperature is not known.

Now, that is about the energy balance, I mean for a particular channel if we have this kind of channels and we will try to estimate what is the total heat that is getting transferred when is you know the fluid is flowing from this end to this end and say if it is some fluid 1 and it may be you know depending on its surrounding fluid, it is having some other fluid on this side and it may be you know for the terminal fluid, it is an I mean end cap would be there for terminal fluid and on this side, there will be another fluid say fluid 1. If it is fluid 2, it will be on this side.

So, it will have interaction I mean depending on the temperature difference, either this fluid will give heat or it will receive heat and when we have fluid stream I mean and it is having some edges and fluid stream and if it is cold or hot, then it will decide I mean whether it has to give heat or it has to pickup heat. So, like this either it may give heat or it may have to give heat to this depending on the situation or the fluids temperature or the situation may be such that it is giving, it is receiving heat and also receiving it from the bottom fluid.

So, there are different I mean configuration that is possible and the stimulation has to take account of that at you know situation. So, basically what we need is fin equation.

(Refer Slide Time: 26:50)



If you remember that in last class, we have in one of the earlier classes, we have tried to solve the fin equation where fin is connected between two surfaces or combined between two surfaces say TA and TB and we try to find out a solution TA and TB and they are connected by thin fin and we try to find solution for this one and there we have been able to find out the temperature profile for that fin and that was theta x given by theta x and theta x was optioned as theta A multiplied by 1 minus omega and e to the power m x plus omega into e to the power minus m x and this is all this one is multiplied by this, where omega is equals to e to the power m l minus r, where this l is the length of this fin and this is in the denominator.

We have sin hyperbolic m l and what is r is just nothing, but theta B by theta A. So, this has been derived from or taken from the paper by BSV Prasad and sorry, and Prasad have it has been published in the journal of International journal of heat and must transfer volume 39 Issue 2 and the pages are 419 to 428 1996.

So, if any one you have to I mean go through it, you can critically look into this paper where you will get this analysis and not only that you can also look into the book we have referred that is the, there also you will find this analysis is available. So, now based on this fin equation I mean we know the fin temperature profile or the temperature profile that is existing in this fin connecting between the two surfaces. Now, once we have the knowledge of this fin temperature profile, we would be able to calculate many things which will discuss in the some of the next classes.

Thank you for your attention.