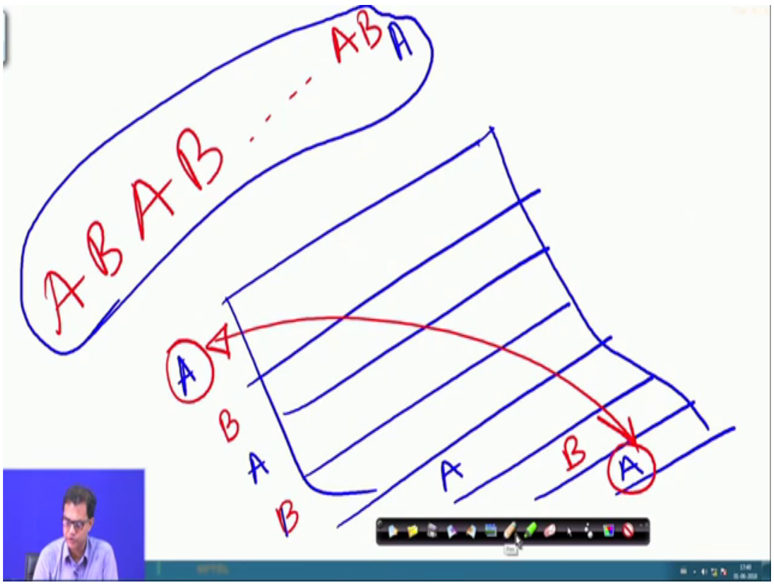
Heat Exchangers: Fundamentals and Design Analysis
Prof. Indranil Ghosh
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 35
Plate fin heat exchanger : Layer Stacking

You all welcome to this lecture. We are talking about the Plate Fin Heat Exchangers and we will now, today in this class we will try to, talk about the Stacking Pattern of The Layer Stacking Pattern In a Plate Fin Type Heat Exchangers and we have, this is particularly important, for multi stream fluid heat exchanger or, though it is equally important in case of a two stream exchanger also, because, in a two stream heat exchangers also, we it is not that, it is limited between only two fluids. That two fluids are again divided into number of layers.

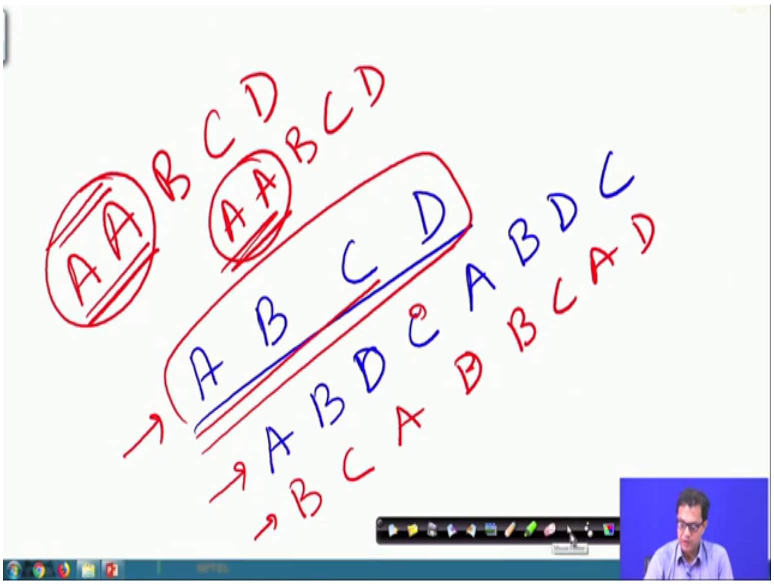
So, it may be such that we have two streams fluid A and fluid B, then this fluid A and fluid B, again, are stacked in different layers like A B A B A B and now, we have in context to one of the problems we said that these A B layers, we when we arrange them together, we put them in A what is called we put in, if this A B the configuration, if we have say fluid number A and fluid B, one of them is a hot and one of them is fluid, I mean cold.

(Refer Slide Time: 01:35)



So, we say that while arranging them, in a plate fin configuration we, put them in alternative usually alternative hot and cold condition and then we put them in this sequence A B then A then A and then in between we have say, this is B and we have B and we say that this hint I mean we always try to put symmetry, between these pattern, I mean ideally, it should have been A B A B and so on, like A B it should end with A B, but generally what happens we put another layer at the end and why do we put, that one to give a symmetry, in this type of configuration. So, that will now, try to learn in this class and particularly, when it is a several streams, we have like, A B and say C and D like that.

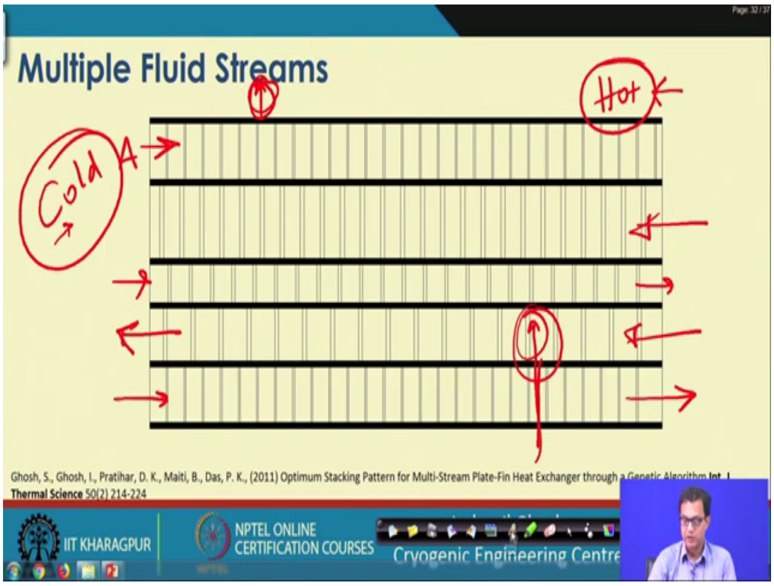
(Refer Slide Time: 03:02)



So, we have different combinations, like we can someone can put it A B then D C and that would be the repetitive one A B D C and someone may think like, putting them in some other combination say B C A D B C A D like that or some other combination. So, there is different type of layer that would, it would result. So, often we have to find out, what is the optimum layer stacking pattern.

So, as you can understand that this becomes a design problem to find out an optimum layer, I mean which optimum layer of which is the criteria to tell that this is an optimum layer or this the best, I mean layer. So, we have to decide so kind of criteria which will correspond to the optimum layer stacking pattern or, sometimes the fluid flow also decides, I mean whether we will be using say, a double like, layer A A B then C D and generally what happens this repetition is to accommodate a very high flooded fluid and then we may again have A A B C D just to, you know accommodate more amount of fluid in a particular, for a particular stream.

(Refer Slide Time: 05:15)



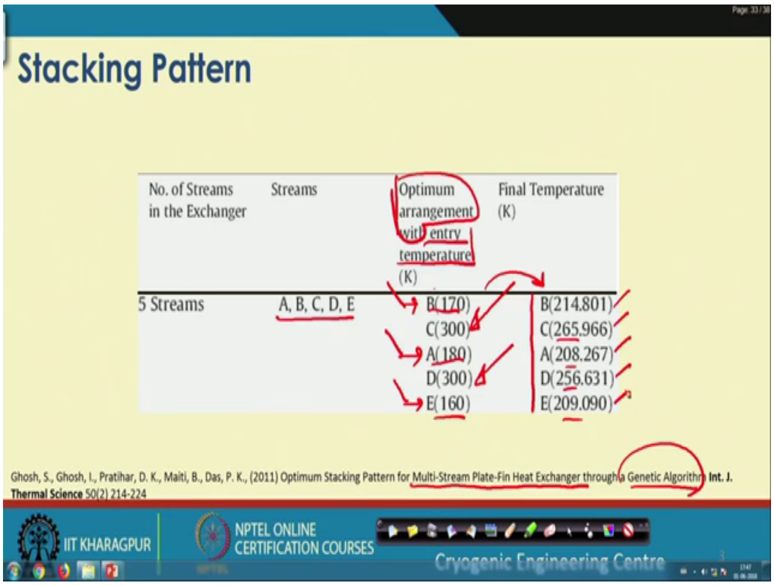
But otherwise, if it is not so, I mean if it is just A B C D or A B C D E or even some other number for fluid streams, we need to find out what is the optimum layer stacking pattern. So, in that context we will see that say in a multiple fluid stream arrangement we may have to, arrange in say like a, then a some fluid moving in this side and some fluid is flowing this way and this is this moving out this side moving out coming in moving out.

And in general, it is all the fluid streams or rather the hot fluid streams we put from one end and the cold fluid stream, we put them in another, in another side and as we can understand that, it is a it may be such that we may have some fluid stream which is not really belongs to the hot one or the cold one.

So, we may have to look for an exact intermediate position where it will have an entry and depending on the it is desired exit temperature we may have to take it out earlier, or we may have to it put it at some intermediate locations.

So, otherwise if we keep this option aside at this moment, that we are not having intermediate entry and exit, but we have clearly some fluid streams where we can distinguish that, this is a hot stream and this is a cold stream, how are we going to arrange them to have a an optimum layer stacking pattern we can call it.

(Refer Slide Time: 06:59)



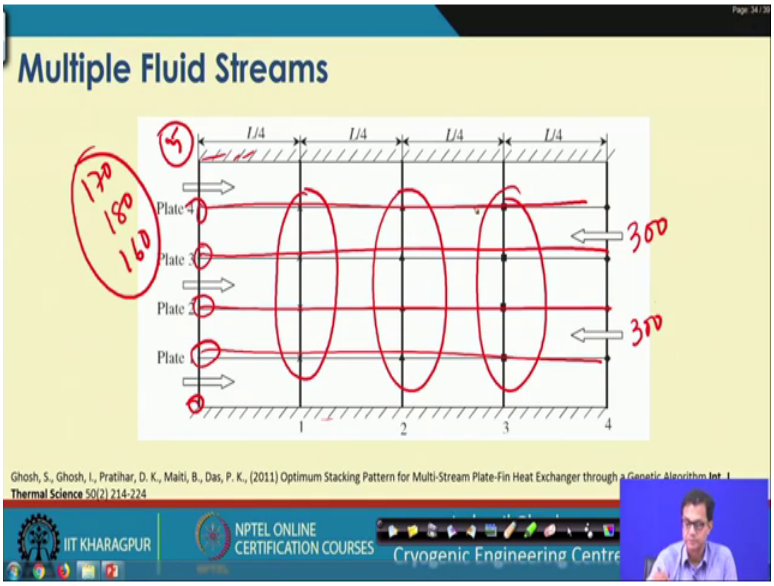
So, let us, look into that first, and if we, actually we will try to, show it to with an example, like here we have say if this the 5 fluid stream, in this 5 fluid stream, some of them are cold stream as you can understand, that the field stream we have 5 field streams, out of which this A and this E and this B, they are clearly these are the entry temperature and we are not say, we will not look into this optimum arrangement.

This is in context to the I mean situation, where we have applied the genetic algorithm to find out the optimum arrangement, but just first of all we look into this problem where we have clearly 3 cold fluid streams and there are 2 hot fluid streams which entering at 300 whereas this cold fluid streams are entering at one at 700 another one at 180 the third one is also again, you know entering at 160.

So, these are clearly the cold streams this 170, 180 and 160. There the cold side stream and other two are the hot streams. Now, if we apply that, as we told that, if we solve that simulation problem, that we have discussed in the earlier classes that multi stream plate fin heat exchanger algorithm will give us the exit temperature corresponding to this.

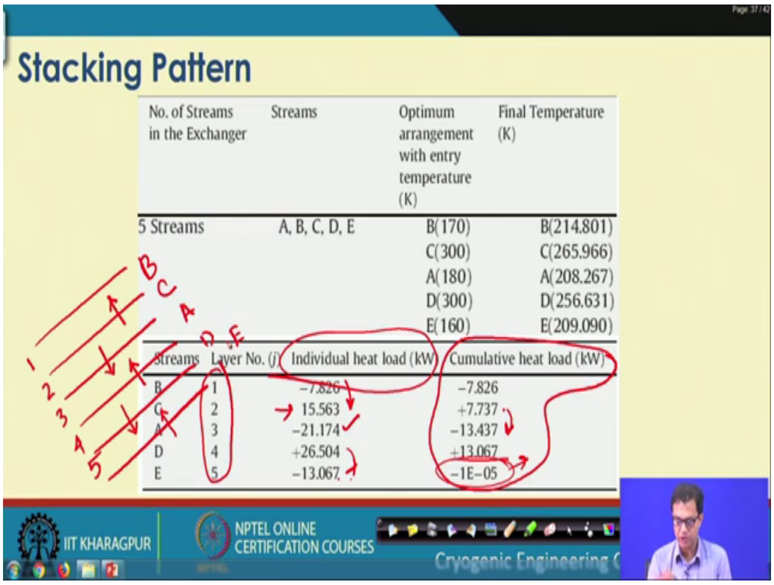
So, the B will come out at 214 then C 265 so on and these are the exit temperature for this fluid streams. Now, we also know the mass flow rate of this fluid streams and the CP of this fluid streams. So, the corresponding, mass flow rate and CP been known to us. We can try to calculate the what is called their heat duties or what is the amount of heat that is getting transferred.

(Refer Slide Time: 09:22)



So, they are basically, as you can that we have, 2 hot fluids they were entering at 300 and 300 and the other one and the 3 were entering at say, 180, 160 and 170. So, like this we had this, arrangement of the fluid streams and then we had these are the separating plates, I mean this was one plate 1 2 3 4 and this plate numbers, we designated as this is plate 1 this is plate 2 plate 3 and plate 4, because this plate numbers are equally important and this is plate 0, of course, this is insulated and this is plate 5th. So, that is again insulated and but we mostly, concerned about this plate temperatures.

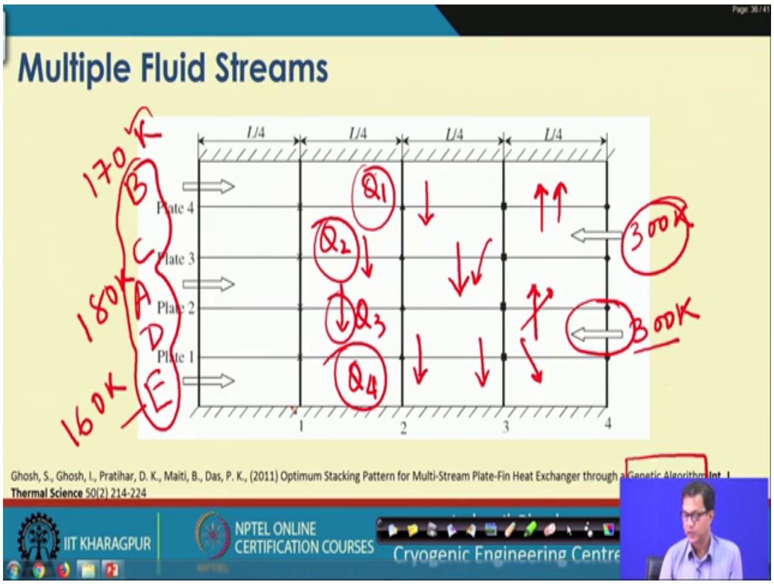
(Refer Slide Time: 10:26)



So, if we now look into this again, as we are talking, that how to I mean, take calculate the heat duty. So, since we know the heat transfer, I mean the mass product and the CP corresponding CP, it was known, it has been given in that paper and we can calculate the, heat load and this is something called the cumulative heat load.

So, if we find that the layer numbered 1 was fluid stream B and then we have the fluid stream C A and D and we can find out what their corresponding temperatures. So, this B actually this fluid temperature if we go back to our earlier slide here, in this we have seen that there are 5 fluid streams.

(Refer Slide Time: 11:16)



So, out of which one is that 300 and this is 300. The first fluid was B then we had C. This is C, then we had A and then we had again D, this was fluid D and this was E. So, this is entering the B entered at 170 degree 170 Kelvin, this is 170 Kelvin, C was entering at 300 Kelvin, then A entered at 180 Kelvin and E was entering at 160 Kelvin.

So, this is the repetitive block, in a multiple you know layer. So, if it is such that this B C A D E combination was giving an optimum solution according to this genetically algorithm program problem. So, we wanted to check whether if it is not always possible to get a genetic algorithm how do we know whether this simulation is an optimum simulation or this pattern is an optimum pattern that B C A D E is an optimum pattern. So, for that the criteria that we have said is that, the cumulative heat transfer.

So, as you can understand that this fluid is giving heat to this one. Similarly, this is a cold fluid adjacent to the hot one. So, the heat will be coming to this side and then this is 300. So, heat will be flowing to this side and heat will be flowing to this side.

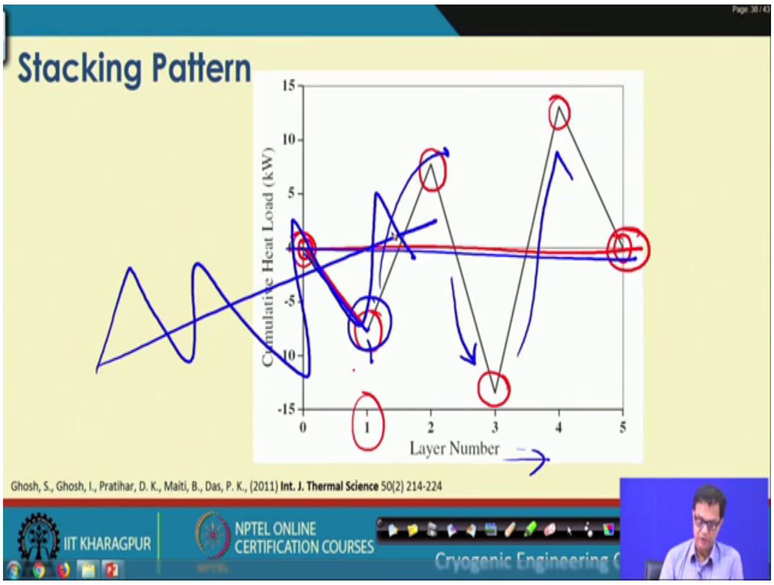
So, from this fluid, this hot base supposed to give heat to this and this is to this side and this hot fluid is again you know, supposed to give heat to this side and this side. Now, individually we if we if we look at this is the Q 1 then we say Q 2 and then we say Q 3 and Q 4. So, deliberately we put this all this down side one as positive. So, if it is you know happening other way then it will be a negative one.

So, this is the individual heat getting transferred Q 1 Q 2 Q 3 Q 4 and the cumulative of their addition. So, we will a have a look into that part. So, here, we have the individual heat loads as we have said that that we may see no that between these two, 3 4 5 layers. So, we have Q 1 that is equal to on this side, so, that S the negative one. So, on this side this is a positive one and there is 15. The next one is on this side, this is equals to a negative part. On this side, this is again you know a positive quantities. So, it is down side and this is equals to 13 minus on this side.

So, we have applied this different, kind of heat you know the cumulative, I mean individual heat load of a corresponding to each plate and now, if we just keep on adding them, you know 7, with 15, it gets big S, becomes a positive then, this positive and this negative gets another positive and this negative, I mean this 13 plus 26 gives positive then you know it, when we combine this 1 with this part, it becomes very, I mean negligible.

So, this we have an energy balance of the order of this type. So, this cumulative heat load as you can understand that, if we put with the number of layers, what is the number of layers? 1 2 3 4 5 and they were B, C, A, D and E.

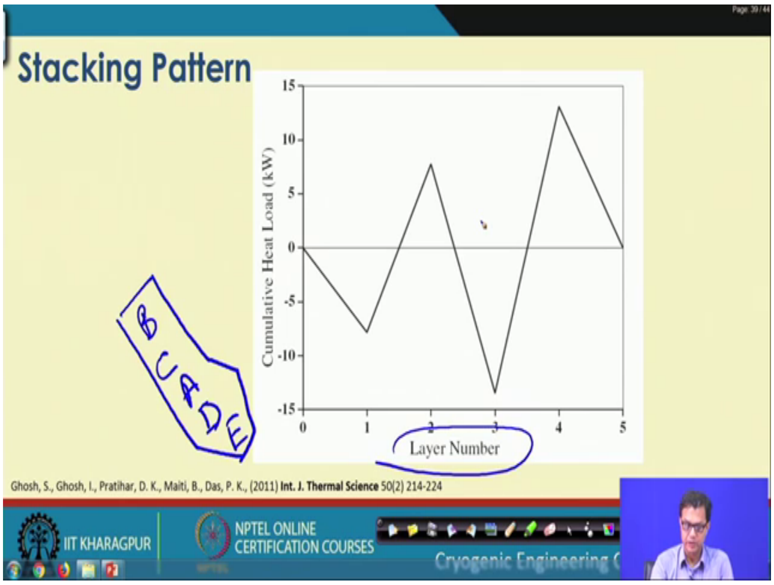
(Refer Slide Time: 16:05)



So, corresponding to this, we have the cumulative heat load and when we a plot them, with a number of layers we find that, what is happening that alternative, the heat load with number of layers, you know it is, it if we considered it to be 0, sometimes it is coming on the negative side. The very next layer, it is on the positive and then it is coming on the negative side. Again, it is going to the higher side and then coming back to this one. So, an indication that the simulation is correct that it will start with 0 and end with 0 and in between this zig-zag pattern, that you know it is coming above the this level.

Sometimes it is according to the number of layers, when we plan in every layer, either it has to be on the negative side and in the next one, it has go to the positive and then, it has to come to negative and like that.

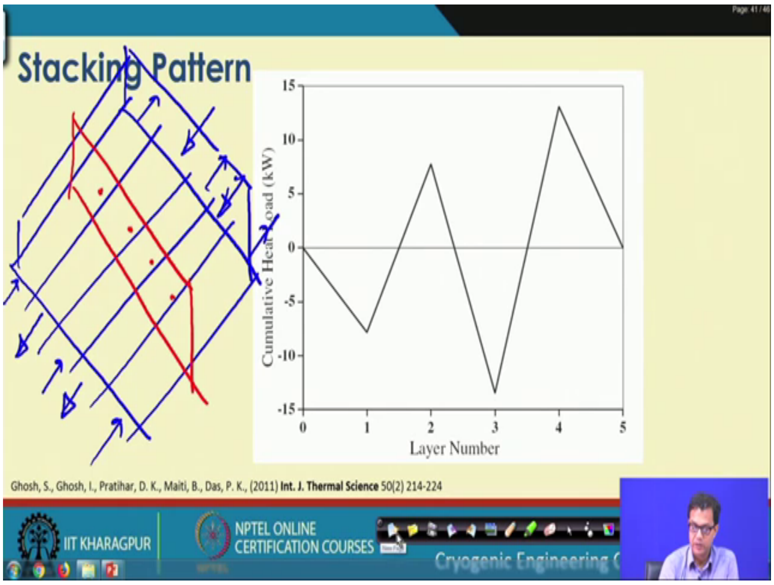
(Refer Slide Time: 17:27)



So, this zigzag pattern will tell that this simulation of this stacking pattern is an corresponding to an optimum stacking pattern and any deviation you know, if in this context, we have said that this was B, C, A, D and E, that was, you know, the optimum stacking pattern we have obtained from that, genetic algorithm, but it is you know and that also shows that this cumulative heat load, when we are plotting it with the layer number that is also reflecting the same that it does zig-zag pattern, in the cumulative heat load; that is also, it is following.

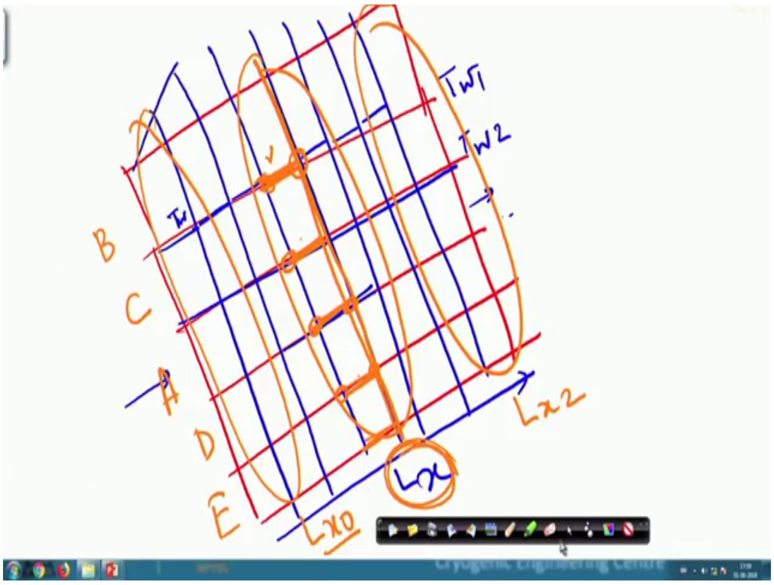
Another indication of this optimum stacking pattern is that, at any cross-section in the heat exchanger in a particular layer.

(Refer Slide Time: 18:15)



You know, if this is the heat exchanger and there are multiple fluids, going in and out so, the optimum fluid stack pattern, it may be such that you may have to put some of the, streams just to one above the other, I mean in the parallel combination or parallel counter combination. But, it may be such that, at any location if we, if other dimension is like this, I mean it is the 3 dimensional one and if we just cut across I mean if we plate, if we slice this heat exchanger, at this plain and if we find out what is the temperature of the plates so, you can understand that the plate temperatures, if we look at, we will find that, these are the separating plates and we have the inlet and the exit temperatures, we have already, calculated and also, we say that our simulation was able to calculate the plate temperatures.

(Refer Slide Time: 19:18)



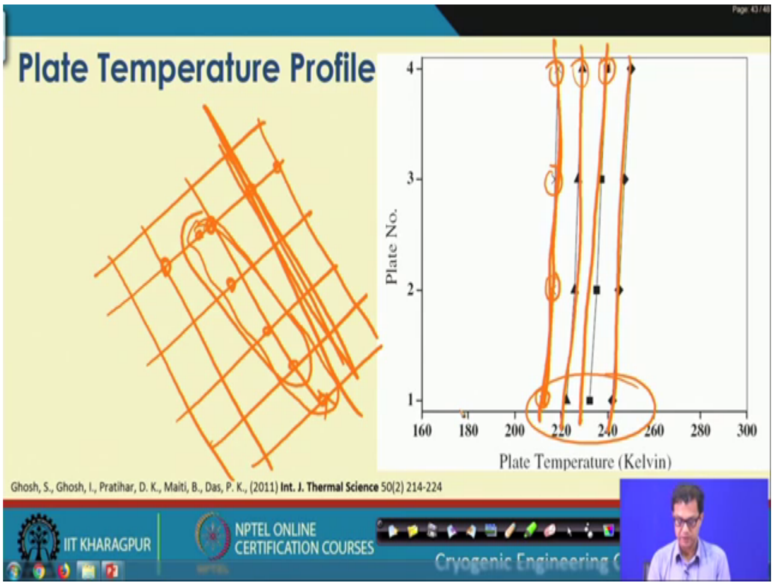
So, the separating wall temperature also TW1 TW2 etcetera and we are able to, when we divide this entire exchanger into small number of segments we can find out what are the intermediate plate temperatures say TW 1 and at this position TW 1, at this position and this position like that, because this is going to vary with length of the exchanger, this is say, the L x and we have the other dimension.

So, this separating, I mean plate will obviously as you can understand that the, the fluid temperature is varying along the length of the heat exchanger and obviously the separating valve will also change with the fluid. Now, at any particular cross section, so that means, if we take or consider this particular location, so, we want to look what is the separating wall plate temperature.

So, between this what is the wall temperature between this two, I mean point, what is the wall temperature. So, at different number of layers, so this is say B C A D and E and we will look into the wall temperature at this particular any cross section at anywhere in the heat exchanger, it may be at the middle, it may be this end it may be on this end anywhere, along the length of the exchanger, but at a particular location when we have to compare we have to compare say, at LX 1 or at LX 2 or at LX0 or something like that.

So, we try to find out what is this, the wall temperature at a particular cross section of the heat exchanger and if we find that they are more or less uniform, then we say that the stacking pattern is an optimum stacking pattern. All we can say other ways that an optimum stacking pattern will follow this kind of temperature profile along the length of the heat exchanger at a particular cross section.

(Refer Slide Time: 22:25)

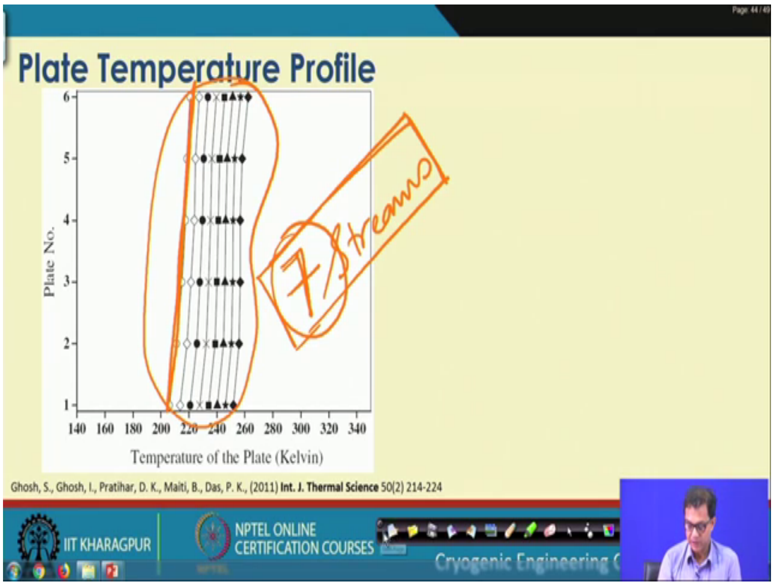


So, for this situation that example that we have shown you, it is first of all following that zig zag pattern for that cumulative heat load and in context to, I mean, in context to the wall temperature, I mean the program was giving us the wall temperature at different locations as we have said that those plate temperatures, we have calculated, sorry the plate temperatures we have calculated and at different positions, I mean say, this is plate 1 2 3 4 like that we have not taken the, so there were 5 plate and these were the plate temperatures, we have considered excluding this one.

So, we have four temperature points and the plate number 1 is having temperature at this and like that, you know, we have for plate number 2, plate number 3, plate number 4. So, like that we had temperature at different locations and they are at a particular location, they are pretty similar and similarly at different state we have actually divided this entire length into that 4 positions and we have noted these four temperatures. If we go back to the original, I mean heat exchanger picture, we will find that there were four such locations, at which all those temperatures were calculated.

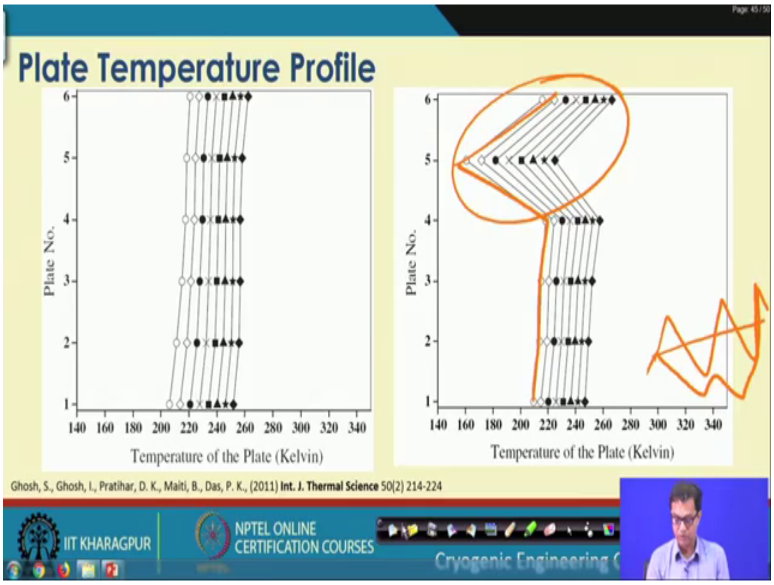
So, at a particular location or a particular cross section we find that the temperature is remaining more or less similar, it is not you know changing much, so that is how we said that this pattern is near or close to an optimum stacking pattern. So, if you know if it is not, I mean an optimum stacking pattern then how it is getting varied that we can see with another example. This is not we will not going to the details of this one, as you can understand that, there are the 7 number of plates.

(Refer Slide Time: 24:16)



So, basically, we have here, I mean 6 number of plates, we have 7 number of fluid streams. So, when the fluid streams 7 number of fluid streams are arranged in a, I mean given optimum stacking pattern corresponding that genetic algorithm, corresponding to that situation, we find that this optimum stacking pattern is giving heat transfer along the length at a particular cross section. This is the kind of temperature at different plates corresponding to the different plates and these are the different locations.

(Refer Slide Time: 25:28)

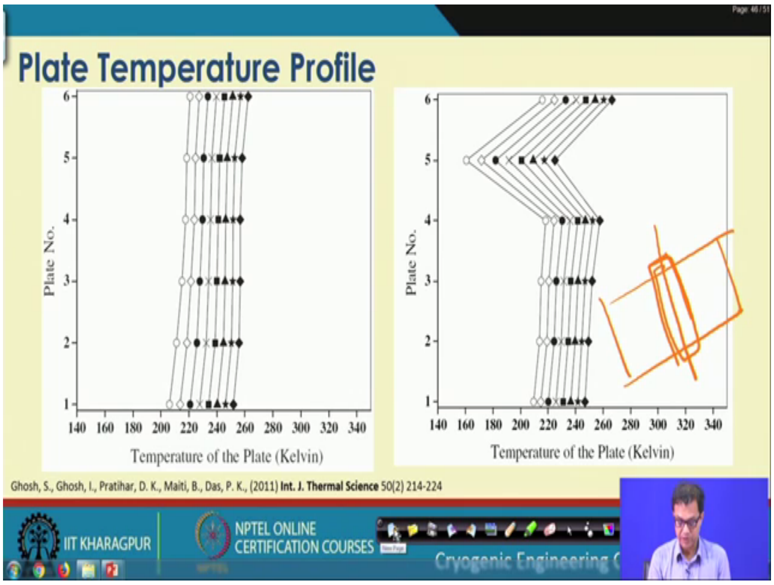


So, what we have is, more or less uniform, but if it is such that, it is not, this is corresponding to the optimum stacking pattern, but if it is not, I mean in that context we will find, that the when it deviating from the actual stacking pattern, we find that the surface called, I mean the plate temperatures are you know, like you know at particular location, this is deviating like this.

And in fact, this will also deviate if you calculate that you know cumulative heat load calculation, if we do it for this configuration also we will find that this will also deviate from that, I mean that cumulative heat load will not have an optimum like zigzag pattern. So, this will also have some kind pattern like this and that will correspond to, I mean a deviation also in the wall temperature or non-uniform wall temperature.

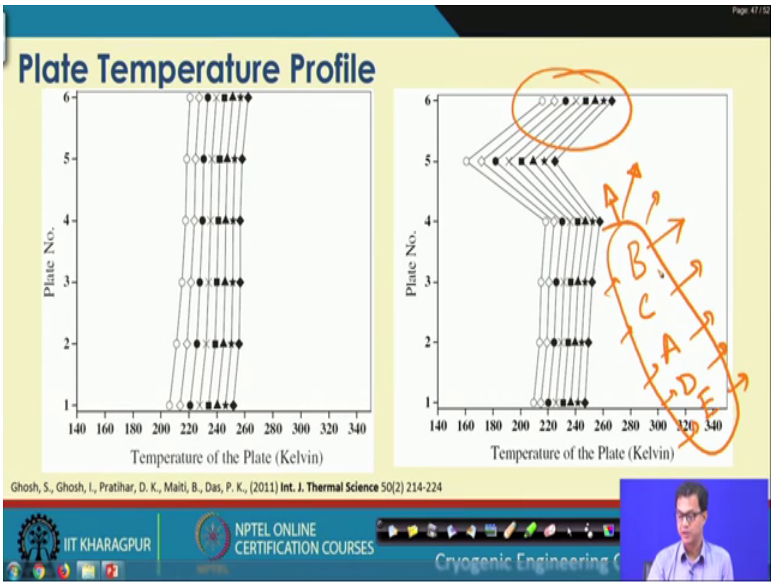
So, this two, I mean conditions like; one is the cumulative heat load and the plot of the cumulative load with the layer numbers, generally is considered as a, I mean criteria for the, optimum stacking pattern and, particularly in case of multi stream plate fin heat exchanger, the temperature at a particular cross section, at any location of the exchanger that uniform temperature in the plate temperature is another criteria to call it as an optimum stacking pattern.

(Refer Slide Time: 26:55)



So, this is all about the stacking pattern and there are multi, I mean rather other than this stacking pattern often we have to, design this is, you may understand that or may realize you might have realized that this particular when we are talking about say, putting the different fluids streams say B C A D E and we had initially this 5 fluid streams.

(Refer Slide Time: 27:40)



And we do not have any information about what would be the possible arrangements and when we have say 7 numbers upstream like this say, in that case situation becomes very I mean critical to physically check exactly what are the optimum stacking pattern. So, in that case we have to go for this genetical algorithm program or some other optimization program to find out, exactly what is the optimum stacking pattern corresponding outputs this we had in particularly in this problem, we try to maximize the heat transfer and we tried to find out the layer stacking pattern corresponding to the maximum amount of heat load.

So, we have to, I mean this is basically, a design problem back and back of this one we had that simulation program, that was basically a rating problem; that means, we were looking for a particular design or this stacking pattern and corresponding to that stacking pattern, what is the simulation or the outlet temperatures at, I means it is predicting that is important. So, a combination of these both this simulation and design goes hand in hand, particularly in case of plate fin type heat exchanger.

So, thank for your attention.