Principles and Practices of Process Equipment and Plant Design
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Module - 03
Lecture - 52
Heat exchanger Network Analysis (Contd.)

Hello everybody. So we were continuing our discussions on Heat Exchanger Network Analysis. And till the last class what we did? We had discussed regarding the location of the pinch. How to we had decided the pinch based on economic considerations and then we had discussed how to locate the pinch.

It was by constructing; there was a graphical procedure by which we can locate the pinch point by the plotting the temperature versus enthalpy plot. And then we had discussed the problem table algorithm which is a much more easier way of locating the pinch point. Now, after we locate the pinch point, then how do we proceed? We have located the pinch point.

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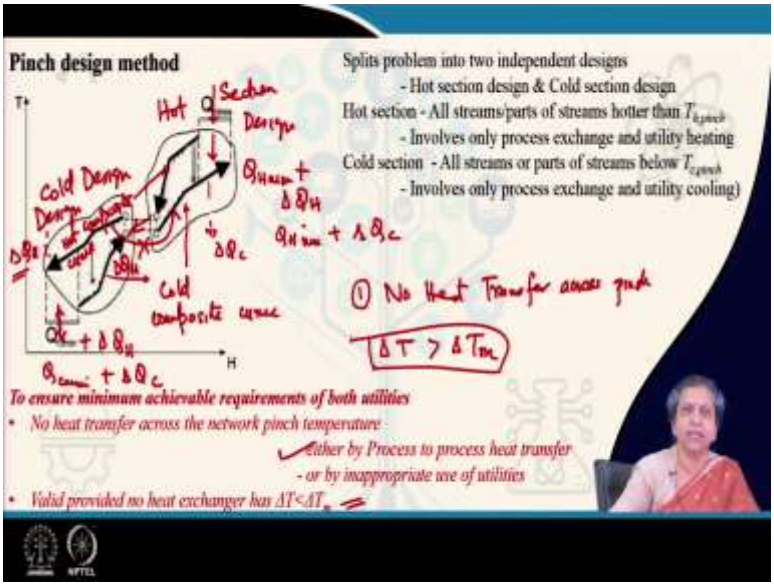

So, after this the next thing what we do is we divide the entire problem into two parts, one part is the hot section design and the other part is the cold section design right. These two designs they are divided just change it yeah. So therefore, we simply divide the entire range into two parts. One part is above the pinch, one part is below the pinch and we say that these two parts they can be designed independently.

Now, the first question is why can they be designed independently, why cannot we assume that there will be some interaction between the hot streams and the cold streams above the pinch and below the pinch, let us see. Before that I like to mention in the hot section what are the things that are there, there are some process streams and there is a hot utility on the top, from here there is an addition of hot utility.

So therefore, suppose I assume for the time being that the hot section is independent, it has got no connection with the cold design, which automatically implies that in the hot section the process streams they are in thermal balance with the hot utility which is being supplied. Same way in the cold section we can say that in the cold section as you have seen from the construction of the composite curves, the cold utilities introduced here.

There is no introduction of hot utility in the cold section. So, which automatically implies that in the cold section the process streams they are complete thermal balance with the cold utility which is being supplied, right. So, this is the first assumption based on which the pinch design method starts after we have located the pinch, then we design the two sections separately and we start matching the different streams for heat exchangers.

And whatever we cannot match we compensate it by either addition of hot utility or by addition of cold utility. And from the composite curve we have found out that hot utilities can be added only above the pinch, cold utilities can be added only below the pinch this we have seen based on this the design method starts.

Before we go to the design method it is important to understand why we could have made, what was the logic behind making such an assumption. That there is no net heat transfer across the pinch temperature. Now, let us see. Suppose you find out see in the cold section, we have the hot composite curve here and there is the cold composite curve here.

Above the pinch also this is the hot composite curve and this is the cold composite curve. Now, one thing is for sure that we cannot have any heat transfer from the hot composite curve below the pinch to the cold composite curve above the pinch. We cannot have it quite naturally, because whatever you say there are hot streams or whatever their temperatures are below the temperature of the cold stream above the pinch, so therefore this is ruled out.

Definitely we can have some amount of heat transfer from the hot composite curve above the pinch to the cold composite curve below the pinch, definitely we can have this. Suppose we have this so, therefore initially we have we already know that this particular section is in complete thermal balance.

So therefore, all the exchangers plus the hot utility which comes in they are in complete balance. Now I assume that some amount of heat say delta Q H amount of heat is being transferred from the hot composite curve of the hot of the cold section sorry of the hot section to the cold composite curve in the cold section.

So therefore, if some amount of heat has to be transferred then that amount of heat has to be compensated here from somewhere. So, therefore, on the top then in that case along with Q H minimum this amount of heat delta Q H also has to be supplied. So therefore, naturally the utility the hot utility cost goes up.

In the cold section what do we find? There is an addition of heat this was in complete balance with sorry the arrow was yeah. So, this one complete balance with the cold utility part. So, naturally when some amount of heat comes out then from here also that heat has to be removed. So therefore, definitely we can have this, but that will not be at the minimum utility consumption.

Definitely if there is some heat transfer it increases both the hot utility requirement as well as the cold utility requirement this is number 1. The number 2 assumption was so one thing we have understood that there is no heat transfer across or rather no cross heat across pinch.

The next thing for what did we assume that there is only addition of or rather addition of hot utility occurs only at the hot section. Now in this case also if I assume that well I will be removing some heat from the hot section. Say for example, say I would like to remove delta QC amount of heat from the hot section again the hot section is in complete balance.

So if I am removing some amount of heat from the hot section, this heat has to be compensated, how will it be compensated along with this QH min? Then in that case I would be adding some amount of heat I will be remove adding some amount of heat that amount of heat which I have planned to remove from the hot section, anyway Q C min will be there.

So therefore, in this case also I will find that my total cold utility requirement will increase to Q the total requirement plus delta Q C, the total hot utility requirement will be increasing from Q H min to delta Q C. So therefore, again if I am adding some amount of cold utility above the pinch, then definitely again I am increasing the both the hot as well as the cold utility requirement.

By same logic suppose I would like to add some amount of say delta Q H amount of heat in the cold section, the same logic applies this is another complete balance. So, if I am adding some delta Q H amount of heat that has to be removed by the cold utility. So therefore, the cold utility now increases from Q C min to Q C min plus this delta Q H.

So therefore, my overall hot utility increases again by Q H plus delta Q H min plus delta Q H, my cold utility requirement increases from Q C min plus delta Q H. So therefore, what I find is for definitely we can add cold utility above the pinch, we can add hot utility below the pinch, but that will be at the cost of additional utility requirements.

For minimum utility requirement design if you want to do then definitely there are three things that we have to consider, first thing is that there is no heat transfer across the network pinch temperature. No heat transfer either by process to process heat transfer the way I was telling from the hot composite curve above the pinch to cold composite curve below the pinch, that will also not happen or by inappropriate use of utilities.

These are the two ways by which my utility requirement goes up and the utility requirement goes up primarily in a retrofit application. If you find fire utility requirement goes up you will be finding that it goes up primarily, because either there is one particular or more than one heat exchangers, where there is cross pinch heat transfer which has to be corrected.

Or maybe if you design it properly, you will find that you have given some cold utility above the pinch which has to be removed or maybe you have given some hot utility below the pinch which has to be corrected. For minimum utility designs these things have to be taken care of.

Now here there are two things that I have assumed. First thing is that all of the heat exchangers, the temperature difference between the hot and the cold streams at the entry as well as the exit end of all the heat exchangers is greater than delta T min ok. So, therefore, this is the other assumption that I have made. And the other thing is for this particular case I have assumed that the hot utility that I have that is definitely higher than the highest temperature which is encountered in this design.

And the cold utility that I have that is cooler or that is at a lower temperature compared to the coldest or the lowest temperature that I will be encountering in this particular pinch analysis. So based on this and assuming that all heat exchangers that I shall be dealing with in my design will be having the delta T greater than the stipulated delta T m that I have decided.

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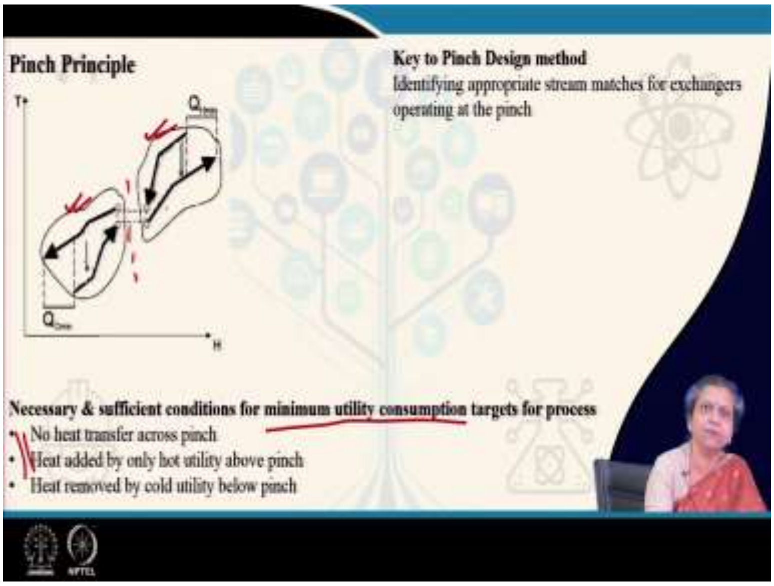

So, based on this the situation becomes slightly simpler, what we assume is that we assume that we can design the hot section as well as the cold section completely independently of one another. So therefore, we will be matching streams in the hot section and whatever we cannot match that will be compensated by the utility.

While we are matching we have to remember that in the hot section we can just add hot utility, which automatically implies that all the hot streams above the pinch point has to be compensated or has to be balanced by the cold streams. We can have excess heat to be removed in the sorry excess heat to be added in the hot section design and so therefore there can be some unbalanced heat in the cold streams.

But for the hot streams all these heat has to be taken away by the cold streams when we are designing the hot end or when we are designing the hot section or the section above the pinch. Same way we have to remember that when we are designing below the pinch, then what we need to do? We need to remember that in this particular case also we can only add cold utility, which means that we can have some particular hot streams which have not exchanged heat with the cold streams.

So, for those unbalanced hot streams we can cool them by adding cold utility, when we are designing below the pinch. But other than that all cold streams have to be balanced by will balanced by enthalpy balanced with all the hot streams when we are designing below the pinch.

And once we have designed above the pinch and below the pinch, then we simply combine the two to get the total heat exchanger network design. So, this is the necessary and sufficient conditions which is essential for minimum utility consumption target, remember this or everything we are talking just to locate the minimum utility consumption.

Remember at the same time in the in industries it is almost impossible to design under the minimum utility conditions, there will always be some but we will always have utility consumptions more than the minimum. The primary reason as I have already told you there will either be some particular cross pinch heat transfer or some inappropriate use of utilities which you cannot avoid.

And possibly by that process we find although we are exceeding the minimum maybe we will be saving on the heat exchanger area number of heat exchangers etcetera. So, that is why we often we have to do this. So therefore, these are the golden principles which are set for the pinch principle, based on them what we do?

After we have identified these things we have located the pinch temperature the two parts. Now the key to a proper design is to identify the appropriate stream matches that will be going such that the exchangers are can take place or that the heat exchange can take place to the maximum possible extent.

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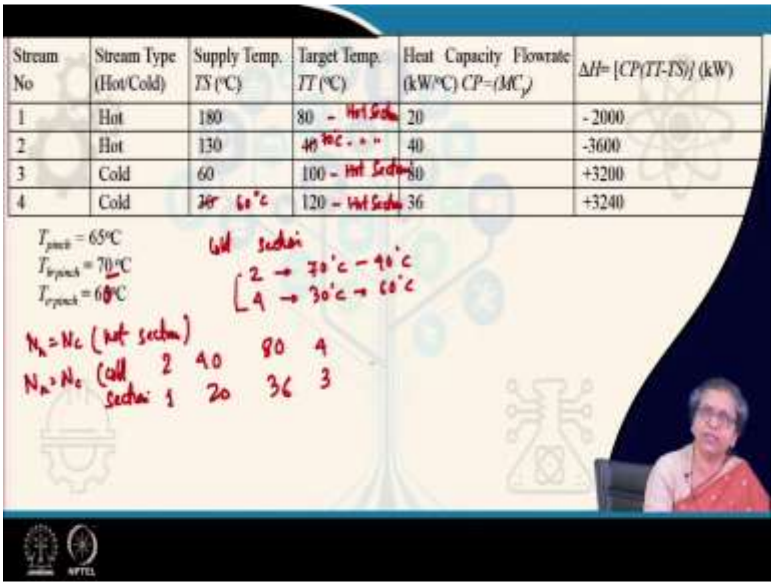

Now, tell me one thing suppose we take up the problem that we had discussed other than the problem which I had given in the beginning of the heat exchanger network design, in this particular case we can very well divide this into a hot end and we can divide it into a cold end.

We know that the hot pinch temperature is 70 degree centigrade. So therefore, we find for stream 1 the entire stream this entire stream will lie in the hot section. For the stream 2 we find that one portion of it will lie in the hot section which portion 130 to this is 70 degree centigrade this will lie in the hot section.

And, in the cold section what will lie? In the cold section for stream 2 from 6 for stream 2 from 70 degree centigrade to 40 degree centigrade will be lying in the cold section. For stream 3 what do we find? 60 to 100 degree centigrade, so therefore this entire thing will also lie in the hot section.

For stream 4 what do we find? We find that for stream 4 from well this I have made a mistake this should have been 60 degree centigrade, from 60 degree centigrade to 120 degree centigrade this part will lie in the hot section. And for stream 4 from 30 degree centigrade to 60 degree centigrade it will lie in the cold section. So therefore, we find that in the hot section we have all the 4 streams, among all the 4 streams what do we have?

We have stream 1 the entire of stream 1 in the hot section, we have part of the stream 2 from 130 to 70 degree centigrade in the hot section. We have the entire of stream 3 in the hot section and we have a part of stream 4 from 60 degree centigrade to 120 degree centigrade in the hot section and in the cold section we just have 2 streams, stream 2 and steam 4.

So therefore, there is not much to think about us, definitely there has to be heat exchange between stream 2 and stream 4. But we have to see that the heat exchange is such that in the cold section remembering that we can give cold utilities. So therefore, the entire cold stream has to be cooled down, if it is if the conditions are such that it is not possible then we have to think of certain other options which we will be talking at the end.

In the hot section we find that there are two hot streams and two cold streams. Now, you can arbitrarily simply take up and start doing the heat exchangers definitely. But again in this particular case I will tell you that if you are thinking about the minimum utility requirement and the maximum amount of heat recovery, it will be nice if we can just go step by step follow certain I will not say certain heuristic rules simply based on logic. And if we can proceed then possibly the situation becomes slightly simpler for us.

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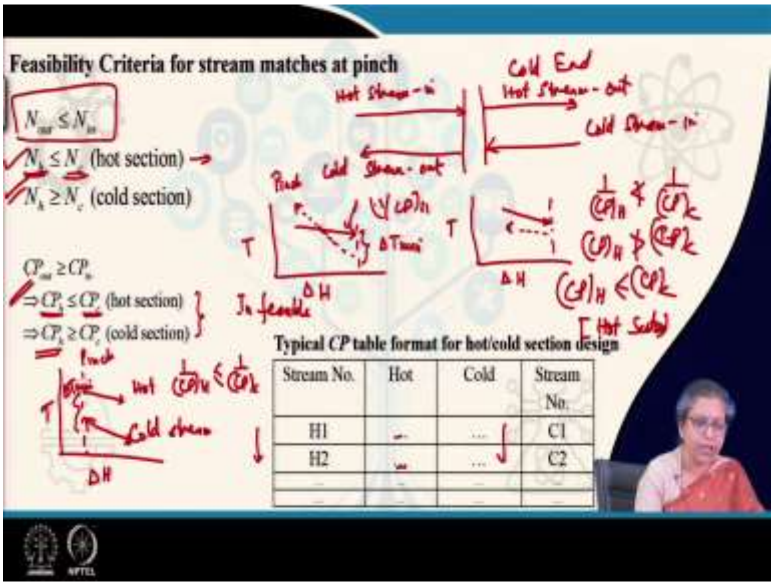

So, what are the logic or what are the basic certain things which we can keep in mind? They are extremely evident, but if you write it down as some sort of rules then it is easier for you to remember. First thing is that suppose we are dealing with the hot section. What do we know?

We know that we can give hot utilities, so therefore if we have some unbalanced cold some unbalanced cold streams we can compensate them by adding of hot utilities. But if we have some unbalanced hot stream or there is unbalanced enthalpy we cannot do it. So, all the hot streams in the hot section have to be compensated by the cold streams.

So, naturally the first condition is the number of hot streams has to be less than or equal to the number of cold streams. It is just the reverse in the cold section because in this case we can add cold utility we cannot add hot utility. So, quite naturally the number of hot streams can either be equal to the number of cold streams or greater than the number of cold streams.

Now just to generalize this particular case we more or less we write it down as suppose we take it down say suppose this is the pinch. So, this is the hot end. So in the hot end what happens? The hot stream it enters the pinch and then in the cold end we find that the hot stream leaves the pinch. Similarly for the cold stream what do we get? The cold stream we always assume counter current flow. So, the cold stream it enters the pinch at the cold end and it leaves the pinch at the hot end.

So therefore, in the hot section we find that the hot stream enters and the cold stream leaves the pinch. In the cold end we find that the hot stream leaves the pinch and the cold stream it enters the pinch. So therefore, just to generalize it for both the sections we have written it down in this way, the number of outgoing streams from the pinch this is from the pinch number of outgoing streams from the pinch.

In either of this section has to be less than or equal to the number of incoming streams to the pinch at that particular section. Now the next part, next part is what? See the in the hot section the CP of h has to be less than equal to CP c. Can you tell me what is the CP h and CP c?

When we draw the temperature enthalpy curves then definitely we had seen that the slope of the curves this is 1 by CP right. Now suppose we are thinking about the say we are thinking about the hot section. So, therefore this is the pinch point right. Now from here what happens? The hot stream in the hot section the hot stream and sorry I have drawn it little differently, I will just rub it off, the hot stream has to be heated here. So therefore this is the pinch and suppose I am drawing for the hot section.

So, in the hot section what happens? I also remove this part, so therefore just in this way this is the pinch right. From the pinch the two streams one stream enters the pinch the other stream leaves the pinch. Say suppose the hot stream is entering the pinch and say suppose the cold stream is leaving the pinch.

So suppose the CP is such that the cold stream slope is in this way. So, we know at the pinch the temperature difference is delta T min. Now if the 1 by CP of the cold stream is more than the 1 by CP for the hot stream, then in that case what do we find that, as it moves out of the pinch and proceeds the temperature difference becomes less than delta T min and there can be another pinch which can happen. And therefore this cannot be an infeasible, this cannot be a feasible situation in this particular case.

So therefore, what is going to be a feasible situation? We are just talking about the hot section. So, the feasible situation will be when the hot section is like this and say the cold section has got a more gradual slope as compared to the hot stream that is going to be a feasible section as far as the hot section is concerned.

So therefore, from here what do we find? We find that in the hot section 1 by CP h that can never be less than 1 by CP cold right or in other words your CP h it can never be greater than CP cold or in other words CP h has to be less than equal to CP cold when I am talking about the hot section.

Same way for the cold section you can do it in the in just a similar way, in the cold section I assume that this is T versus delta H and this is the pinch point. So therefore, in the cold section also if you really want to if you really want to have something feasible, then in that case what should it be?

In that particular case this is the say this is the hot stream and then in that case this has sorry this has to be the cold stream. So therefore, the in this particular case you have to remember that the CP hot or rather1 by CP hot has to be less than 1 by CP cold less than equal to.

So therefore, which automatically implies that, the hot stream has to have a greater than or equal to CP in the cold section. This is just to ensure that since we are having delta T min at the pinch and after that the delta T has to increase. So, beyond the pinch delta T has to be greater than delta T min, so therefore in order to respect that this is the CP criteria which should be obeyed or which should be complied when we take, when we select the streams for heat exchange.

So, these two are the conditions if we keep in mind while we are selecting the streams which we select for mutual heat exchange a life becomes extremely simple. So just to facilitate the this you will find that in almost all text books they have provided a typical CP table. What is the CP table? In that you write down the stream the hot streams here and you write down the CPs in descending order, you write down the cold streams you write down the CPs in descending order.

Moment you have prepared this particular table immediately it becomes evident to you that where you should be doing the matches. So, then in that case the situation becomes much more easier in this case. Let us apply this to the section that we have done. So therefore, in this particular case if we can write down the CPs in this particular way, then in that case what do we get?

We get that for the hot streams the CPs are 40 and 20. So therefore, stream 2, stream 1 for the cold stream it is 80 and 36. So therefore, this is stream 4 this is stream 3. So, therefore, automatically it is quite evident that which are these streams that you will be matching.

Now here I will tell you that since there were just two hot two cold, so therefore life was much simpler for us. In this case what did we observe? We find that N h equals to N c hot section you are extremely fortunate N h equals to N c cold section. So therefore, criteria number 1 that is satisfied, now for the criteria number 2 you can match and we can proceed accordingly right.

Now once you have realized that what are the streams that you will be matching, so therefore in this particular case quite naturally you will be matching streams 1 and stream 4 and stream 2 and stream 3 more or less it is quite evident. So, therefore this part is done. Now after you have matched the heat exchangers the next thing is what will be the load on the heat exchangers.

Remember one thing if the if you can put the maximum possible load then in that case definitely you require the minimum number of heat exchangers. So, once the this part was there for the minimum utility design, for ensuring the minimum utility design these are the 2 conditions that you are supposed to follow.

Based on this you have now decided upon the matches, once you have decided upon the matches now how to decide upon the load. You will decide on the load in such a manner that the number of heat exchange units become less. So, in that case what do you do? I will just do the exact example and show you the thing is that from here you select the exchange select the stream which has the lower heat and try to extract the entire amount of heat by the other stream.

Then in that case with each particular heat exchange you are simply cancelling 1 1 stream and that will ensure the minimum number of heat exchange units.

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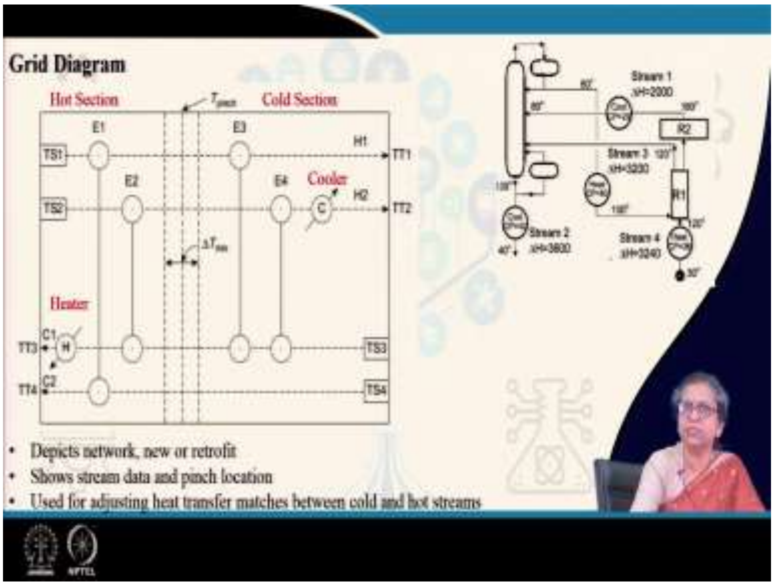

This particular thing this is known as the Tick off heuristics.

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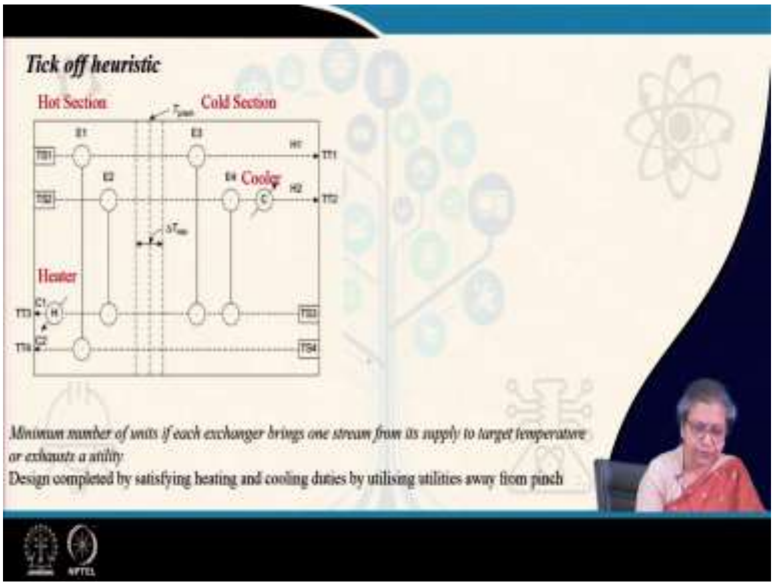

So in order to go for the tick off heuristics what we need to do is we the normal thing that we do is we arrange the whole thing in the form of a Grid diagram. What is this grid diagram that we do? This grid diagram is an alternative representation of the hot stream methods that we have here right. So, this was the original problem, in this particular original problem I have just shown all the streams, in this particular original problem I cannot divide it below the pinch above the pinch and continue doing it.

So therefore, an alternative representation is the grid diagram. So what we do in the next class we discuss the grid diagram, what it contains and then how we decide on the matches.

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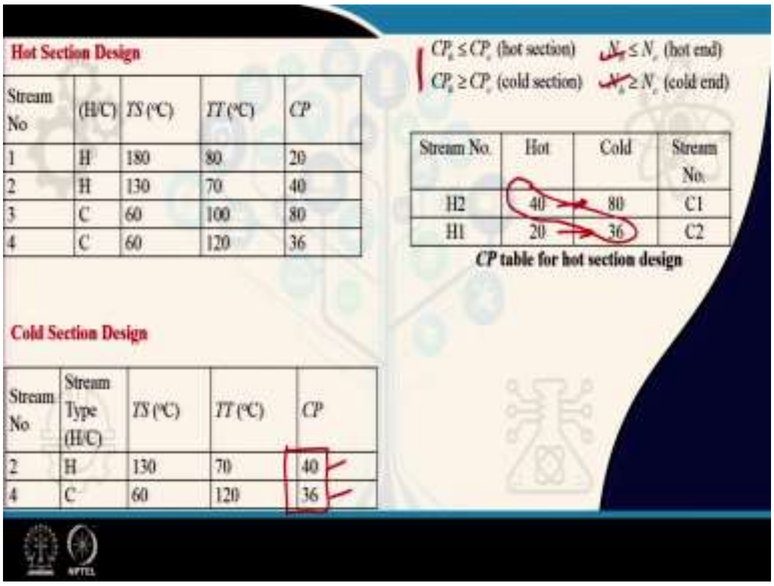

Based on this we are going to work out the problem which we have already which is already given to you and then we start proceeding with the matches. So, I will just mention that in the hot section just as I had written down here, this is simply written down. So therefore, you know very well that what are the things in the hot section what are the things in the cold section, cold section is pretty simple just two streams. So, we do not bother we have made the CP table for the hot section.

And whenever you make a CP table be very sure to write down the criteria so, that it is there with you for your case both this and this they are satisfied you I have already mentioned. And then again for this you find that in the hot section CP h has to be less true for this case CP h has to be less true for this case. So, from there it is evident suppose you would have without understanding you would have selected to exchange heat between H 2 and C 2 that would not have happened ok.

So that is why it is important just for convenience, there is no logic file where they arrange it in descending order etcetera. The convenient thing is blindly simply you write down the streams you write down the CP hot stream this side cold stream this side. And write down the stream such that they are arranged in the descending order of CP.

Immediately the matches that you have to make becomes evident for you and in the cold section also if you compare the CPs you find that in a cold section the CP hot has to be greater than the CP cold very fortunately this is satisfied. So therefore, your criteria for the pinch design they are satisfied both for the hot section as well as for the cold section.

Now we go for matching them for matching them we decide upon the rather we construct the grid diagram and then we go about matching. While matching what we have to remember suppose we are matching between H 2 and C 1, we will find out where the enthalpy is less. Wherever the enthalpy is less, we would try to extract the entire amount of heat by this heat exchange. So, in that way we are going to minimize the utility consumption this part will be doing in the next class.

Thank you very much.