Principles and Practices of Process Equipment and Plant Design
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Module - 03
Lecture - 53
Heat exchanger Network Analysis (Contd.)

Hello everybody. We will be continuing with our discussions on the Heat Exchanger network. So, in the first class what we did, we located the pinch point. We discussed two methods, one was the graphical technique for under for explaining the concepts and then the technique which is going to be useful for you when you actually find out the pinch temperature, it was by the problem table algorithm.

Once we could locate the pinch point then we had divided the design in a hot section design, that is the design for the section which is above the pinch temperature and the cold section design that is the design of the section which is below the pinch temperature. Now once we have divided it, now we start matching now for matching there were certain criteria ok the what was the criteria, there was a CP criteria and there was a number of streams criteria.

So therefore, we had discussed those particular criteria and then we are we were about to apply it to the problem that we had discussed and for that I had said that once we have decided everything.

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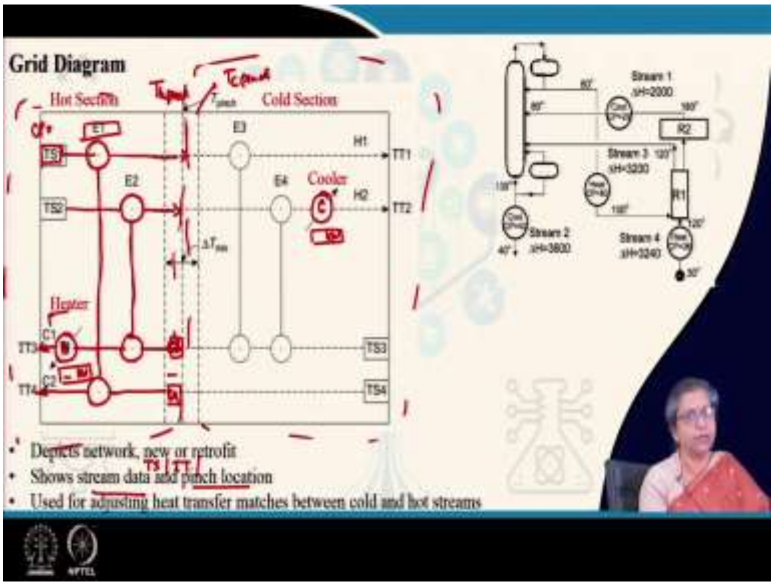

Then what we do is the conventional thing is we represent the hot section as well as the cold section separately in two grid diagrams. Now what is this grid diagram, this is simply an alternative form of representing the heat exchange heat exchange streams before the pinch and after the pinch and there we represent both the stream data as well as the pinch location and also we show the heat exchange the heat exchangers between which streams they are located and where the hot and the cold utilities are located.

This grid once we have designed for the hot section and the cold section, we combine the two. I have just put a typical grid diagram after combining when will be designing the hot section. We will just be concerned with this particular portion, when we will be designing the cold section we will just be concerned with this particular portion then we combine the two and we proceed.

Now in a grid diagram there are certain things certain means certain norms which are followed if you follow them then definitely your things will be much more systematic, it is not that you have to do it, but if you do it then thing is going to much more systematic. In a grid diagram what we do, we will depict the different streams by convention the hot streams are located above the cold streams.

So, we locate first the hot streams. How do we locate them, we show the we write the stream number here. Normally here we write down the CP value and we also write down the start temperature here and then we extend till the pinch, the pinch temperature generally we write down the for the hot case we extend till hot pinch, for the cold case we extend till the TC pinch.

So therefore, the pinch temperature will be written down here, the start temperature will be written down here. This we do for all the hot streams. We arrange all the hot streams in this particular way to start with right, we arrange the hot streams. Once we have located the hot streams in any particular order then we start locating the cold streams. So, for the cold streams again what do we do, when we are doing the hot end design they are going to start from the pinch temperature will be written from there they will be coming out.

So therefore, here I will be writing the target temperature, here I will be writing the start temperature and normally here we put it as say c 3, we put it as say c 4. We write down the in this case the start temperature is the pinch temperature and then we simply extend it and we need to show the arrows also.

So, for the and we are always doing everything for pure counter current heat exchangers. So, therefore, we will be showing a counter current arrangement, the hot streams they will be moving from the left end to the right end, cold streams will be moving from the right end to the left end and the hot streams will be shown first, the cold streams will be shown later.

Once the streams are located the CPs the start temperature end temperatures everything is given, then we already know for which are the streams where we will be matching. So, therefore, the heat exchangers they are shown by two circles on the two streams across which heat exchange will take place and they are connected by a straight line.

So, for all particular process heat exchangers which take place, once we have identified the streams then from those two streams we place two circles and we connect them by a straight line which shows that heat exchange is occurring between these streams. If you want you can number them as E 1, E 2 etc. etc.

After you have done it after all the heat exchangers are placed then you need to find out what is the unbalanced enthalpy based on whether the heat has to be removed or heat has to be added, you are going to locate heaters and coolers. Its already known to you that heaters will be in the hot section coolers in the cold section. How do you show a heater, it will just be a circle on the stream where you have located it with H written down.

Same way a cooler will just be a circle located on the stream where it is rather placed on the stream from where it has to remove the heat and it is shown by a C here and here you can also write down this much kilowatt or whatever which has to be removed. Here you can write down not here in this case below the arrow you can write down this much kilowatt which has to be added right.

So therefore, and for all the exchanges you can write down the amount of heat exchange that is taking place across the particular streams. So, once you have arranged the whole thing, this grid diagram you remember one thing it is supposed to show you stream data, this not only stream data the start temperature, target temperature, the direction everything. It is supposed to show you the pinch location and it is also supposed to show you the heat exchange schemes the streams across which heat exchange is taking place and the placement of the heaters and coolers.

So therefore, this is a complete diagram which is used for adjusting the heat transfer matches between the cold stream and the hot stream this is done both for the hot section ones, cold section ones, once the two are done then they are combined and we get the complete picture.

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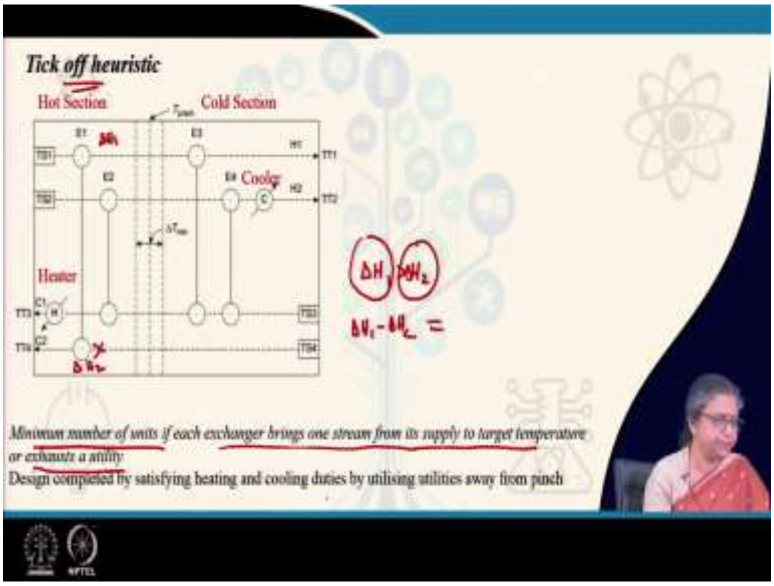

And after this the next thing only which is left is the Tick off heuristics. So, naturally suppose in this particular case there is heat exchange between the two. You know that the amount of enthalpy that has to be removed from here is delta H 1 and the amount of enthalpy that has to be removed from here is delta H 2 right and you suppose you know that say delta H 1 is greater than delta H 2.

So therefore, by this particular exchange the entire delta H 2 heat can be removed and after that there will be some amount of delta H 1 minus delta H 2 heat in the stream 1 which has to be removed either by exchange with some other cold stream or maybe by a process utility.

So, therefore, whenever we are exchanging heat between rather we are placing a heat exchanger in order to ensure that we are having the minimum number of exchangers, maybe it will add up on the area, but for the minimum number of exchangers the heat exchanger has to nullify one particular stream. On other words it has to take up the complete amount of heat from the streams which has the lower amount of heat whatever after that is taken up.

So, naturally this suppose in this case, this stream has been nullified the entire heat has been taken up. After that we find what is the balance heat that could not be taken up, then we find out if there is any other cold stream from with which this balance can be adjusted and it can be taken up. So, normally we find that for all the hot streams they can be adjusted by adjustment with the cold stream.

For cold streams maybe we might not find a heater hot stream in this particular case. If after all matches we do not find a hot stream we place a heater. I am just talking about the hot section, the same thing applies for the whole section as well.

So therefore, the first thing what you did first thing after locating the pinch point after identifying the streams, you first draw the grid diagram and then apply the Tick off heuristics which as it is written down it ensures the minimum number of units, if each exchanger brings one stream from its supply to target temperature or it completely exhausts the utility and then we complete the design by satisfying the heating and the cooling duties which could not be satisfied by the process exchange.

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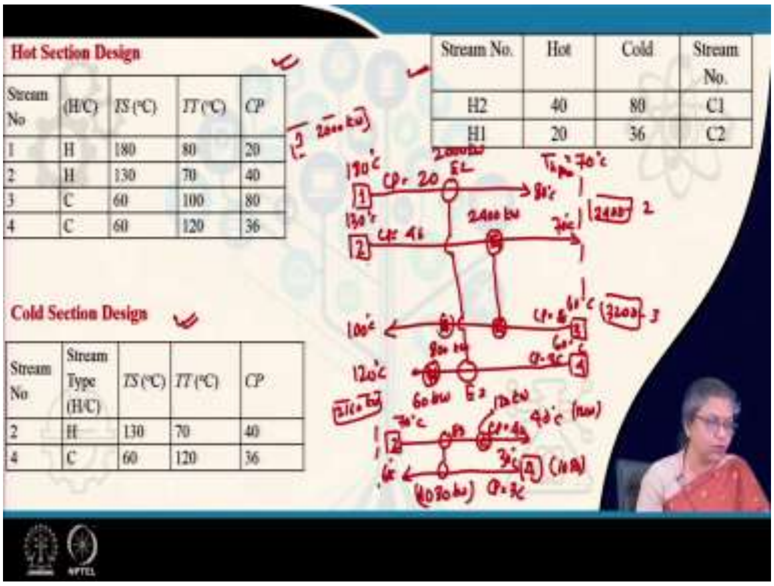

So, this is the logic by which we proceed. Now in that with all these things now let us start for the hot section and the cold section in this particular case. The details are provided here. For the hot section I have done it separately, cold section I have done it separately. I have prepared the CP table just for the hot section because the cold section it has got just two streams. Now for this suppose I start drawing the grid diagram. There will be stream 1 from where does it start 180 degree centigrade, it is going to end at the pinch point.

So therefore, what is the pinch point in this particular case its going to end slightly before the pinch point because it does not go till the pinch point. So, therefore, in this particular case the pin what is the pinch point here the pinch point is for the hot stream it is th pinch equals to 80 sorry, 70 degree centigrade. This is going to go till 80 degree centigrade and I am going to place the CP here CP equals to 20.

Next stream, stream 2, in this particular case it starts from 130 degree centigrade and it extends till 70 degree centigrade right. The CP in this particular case is 40. Next I start stream 3, stream 3, I locate here It comes in this particular direction from it starts from 60 degree centigrade comes to 100 degree centigrade. The CP of this particular stream this is equals to 80 is not it. CP is 80 yeah and the fourth stream, again the fourth stream from where is it going to start from 60 degree centigrade it is going to start it is come to going to come to 120 degree, centigrade CP in this case is 36 perfect.

So I already know where I am going to place the matches this is very clear from here. So, I start placing the matches between H2 and this one and here if you calculate it you will find that for the hot stream the total amount of heat that has to be removed that is 2400. You can just calculate and find out for the cold stream the amount of heat that has to be removed is 3200. So, what I do? I remove this 2400 kilowatt of heat in say exchanger E 1 moment I have removed. So, therefore, this stream is completely satisfied.

What do I have in this particular case I have got some amount of unbalanced heat, this unbalanced heat is 800 kilowatts. This I cannot satisfy by interaction with your stream 1, you can very well known because of the your CP mismatches. So, in this case I have no option. I have to put a cooler here. This cooler will be removing this 800 kilowatt of heat in this particular case this part is satisfied.

Now these two streams. Across these two streams also, I can put a heat exchanger, this is exchanger E 2, now here if you see for this stream the amount of heat that has to be removed I will just write it down roughly, stream 1 this is this, this was for stream 2, this was for stream 3.

So, this much amount of heat has to be removed ok and in this particular case if you find the amount of heat enthalpy which it contains is 2160 kilowatts. So, therefore, naturally for from this particular exchanger, what I can do I can simply remove 2000 kilowatts of heat, moment I removed moves this streams enthalpy balance is satisfied.

So therefore, after this I find that 160 kilowatt of heat has to be removed, there are no hot exchanges from which it is heat can be exchanged. So, what I do? I place another cooler which is going to remove 60 kilowatts of heat here hot section design it is ready in this particular case.

So, now, I do the cold section design. Cold section design it is pretty simple. You are having a stream 2, again this stream 2 it goes from 70 degree centigrade to say 40 degree centigrade. The pinch is here and then you have got another stream, this stream is I think fourth stream 4, you have here this stream 4 from it goes from 30 degree centigrade to 60 degree centigrade right the CP for this is 36. CP for this is 40. So, therefore, you place a heat exchange here.

So therefore, in this case what do you find that for this the enthalpy requirement is about 1200, for this enthalpy requirement is 1080. Quite naturally the heat exchanger it this is going to be E 3 and this is going to remove 1080 kilowatt of heat. So, that this stream is completely satisfied.

There is some excess particular heat which has to be removed from this stream. So, since there are no other exchanges what do we do? We simply put a cooler here. There is one sorry maybe I have made a mistake this one yeah sorry, in this particular case is a hot end so, I am sorry there has to be heaters very sorry. So, therefore, there are heaters here and here I have put a cooler in this particular case.

So this particular cooler this is going to cool it from this it requires 120 kilowatts and then that cools this particular stream. Actually what I should have done is I should have placed the cooler on this side that should have been the correct thing. I will just do it that should have been the correct thing I am sorry about it. So, therefore, the cooler should have been placed here and this cooler would should be having 120 kilowatts of heat it should be removing right.

So, therefore, the cold end design is satisfied, the hot end design is satisfied in this case. Once the cold and the hot end designs are satisfied. Now, what you can do? You can simply combine the two and you can prepare the entire grid diagram.

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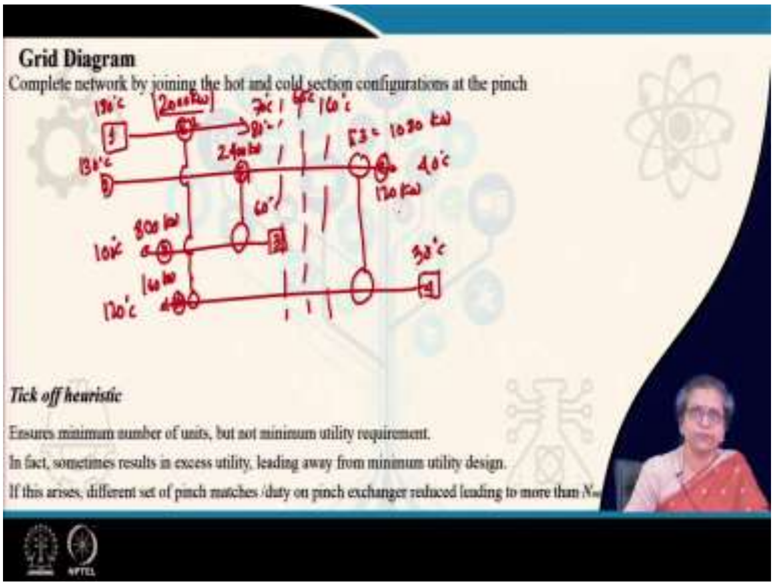

I think that is not going to be very difficult for you. I will just show this in this particular case. You are supposed to show the pinch temperature. So, therefore, this is I think 65 degree sorry, this is going to be 65 degree centigrade. So, this is 70 degree centigrade, 60 degree centigrade.

So therefore, this starts from again the same thing you have to do the, this will not go to that extent yeah. This is 80 degree centigrade and then there is stream 2 which will start from 130 degree centigrade go right up to 40 degree centigrade. Then you are having stream 3 which is going to start from 60 degree centigrade, stream 360 degree centigrade, then it will last till 100 degree centigrade and then you are having streams 4, which is going to start from this is 4 this is going to start from 30 degree centigrade.

It is going to extend 120 degree centigrade and then the heat exchangers we have already done. There is going to be one particular heat exchanger which is going to take up 2400 kilowatts. There is going to be one particular exchanger here which is going to take up 2000 kilowatts. I have forgotten the numbering if this is E 1 then this is going to be E 2 and then there is going to be two heaters here H 1 and H 2.

So they are going to 800 kilowatts, 160 kilowatts and then in this particular case there will be one other heater exchanger which is E 3 and this will be taking up 1080 kilowatts and there will be one particular cooler here which will be taking up 120 kilowatts. Now if you add up you find that the total amount of hot utility requirement is 960, cold utility requirement is 120 and the entire thing is balanced in this particular case. So, the entire grid diagram is ready for you.

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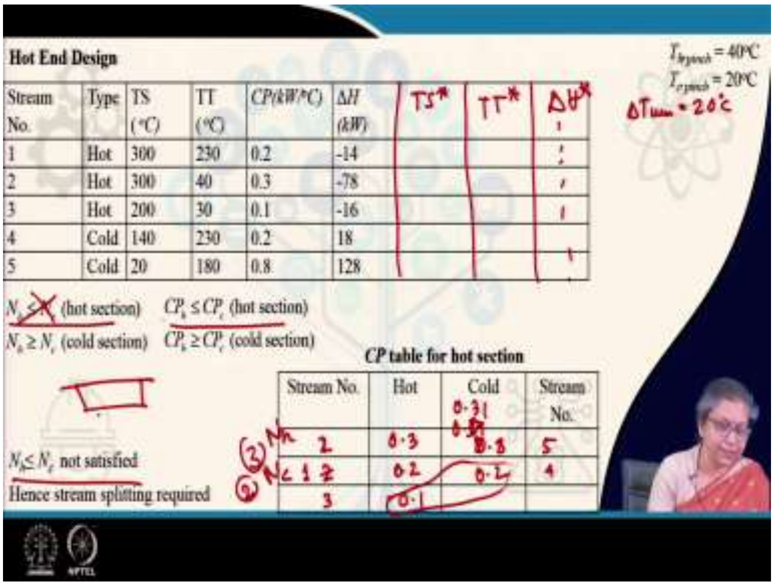

This problem I should say this was quite simple in that particular way and so therefore, this situation was slightly easy right because all the CP matches the your NH was equal to NC and all those matches they were satisfied. So, therefore, the situation was slightly better and so therefore, we could do it.

Now I will be taking up one more problem for you. The specifications of the problem they are given here. In this particular problem we have three hot streams and we have two cold streams the start and the target temperatures are given, the CP is given the total delta H acquired is given.

Just the way we had said from here you can start you can find out TS star and you can find out TT star and then you can find out delta H star between each particular interval just the way we have said locate the position where you have got the maximum minus delta H, apply this as the hot utility on the top. Adjust all the enthalpies which is moving from cascade to cascade and then find out finally, what you are going to get.

In this particular case you what you will be getting is your th just let me see if I have got the details yeah, what you will be getting in this [FL] the delta T min also in this particular case I had specified that in this I am doing this work for delta P min equals to 20 degree centigrade.

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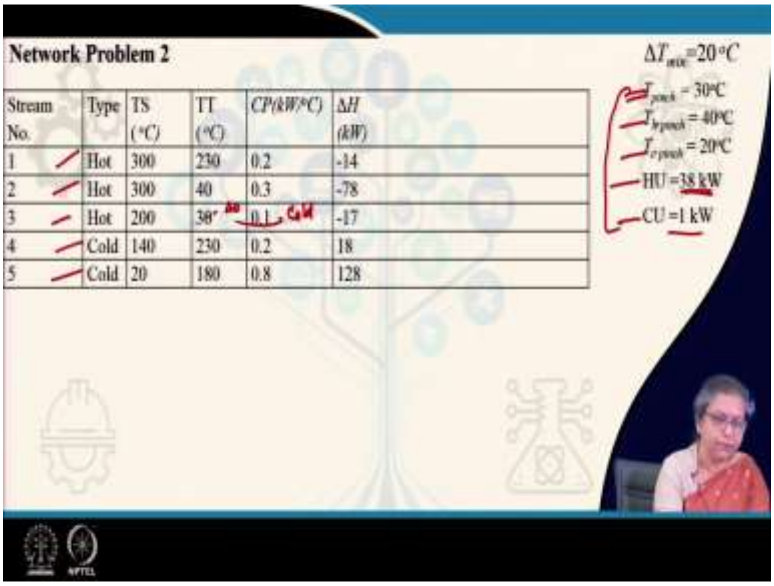

Now, if you have done the whole thing then in that case you will be finding that the pinch temperature is coming to 30 degree centigrade, hot pinch naturally 40, the cold pinch naturally is 20 degree centigrade, total hot utility requirement is this one and the cold utility requirement is this one. This entire thing you can get either from a grand composite curve or in fact, the slides were just interchanged, you can either get this from a grand composite curve or you can get it from the pinch problem.

Now once this whole thing is done, now we can; now we can start dividing between the hot section and the cold section. So, therefore, you will find that in the hot section this 300-230 this will lie to completely in the hot section, we will find this 300-40 this is also going to lie in the hot section and for this particular the stream the stream 3 you will find that from 200-40 will be lying in the hot section and only a very small portion of it will be lying in the cold section.

If you again see this, if you again see this you will find all of these will be lying in the hot section. In the cold section what do you have just one particular stream which is going to extend. So, you do not have to do much about the about the cold section. What you need to do you just need to cool whatever enthalpy is required and for that you need a cooler here so this design is not much involved. We are not going to do what the hot section now let us start.

So, therefore, in the hot section, now if you see what do you find that we have all the streams 1, 2, 3 everything. So, therefore, 1, 2, 3 now let us arrange them. So, therefore, stream 2 should have come first 0.3, in this particular case stream 1 which is 0.2, stream 3 which is 0.1. For the cold section if you arrange your stream 5 which is 0.8 and then comes stream 4 which is 0.2.

Quite naturally you now you can find that one match has to be made by this, this is very evident, but before we think of matches let us see whether everything is being complied or not. What are the things that we that we have to comply, we are just talking about the hot section.

So, this is one criteria, this is the other criteria. If you find that this criteria more or less it is being complied, what about this criteria for the number of hot streams has to be either less or equal to the number of cold streams in the previous problem NH was equals to NC fine in this case you find that actually you are having three hot streams and two NC.

So therefore, this particular criteria this is not being complied, this is not satisfied. So, what to do it, you have to design it in such a way that all the criteria are complied. So, therefore, since you are having one less cold streams, what we do is we simply split one cold stream and make it equal to the number of hot streams. Which cold stream are you going to split, this split is going to be a parallel split. So, that the CP gets split between the two naturally. The stream 4 it has got a very less CP, we will not like to do it.

So, quite naturally what we would be like to do we would like to split this particular CP right and we would like to split stream 5 into 2 particular streams such that one stream exchanges heat with stream 2. One stream is going to exchange heat with stream 1. How are we going to split it, we have to split it keeping this into mind; that means, we have to split it in such a way that the after splitting also the CPs of this has to be more than the CPS of this.

So, therefore, it in that particular way we have to split it can be 0.31, 0.29 sorry it can be; it can be 0.39, and 0.59 and in that one different particular ways you can split it. So, let us do what we do and how we split it right.

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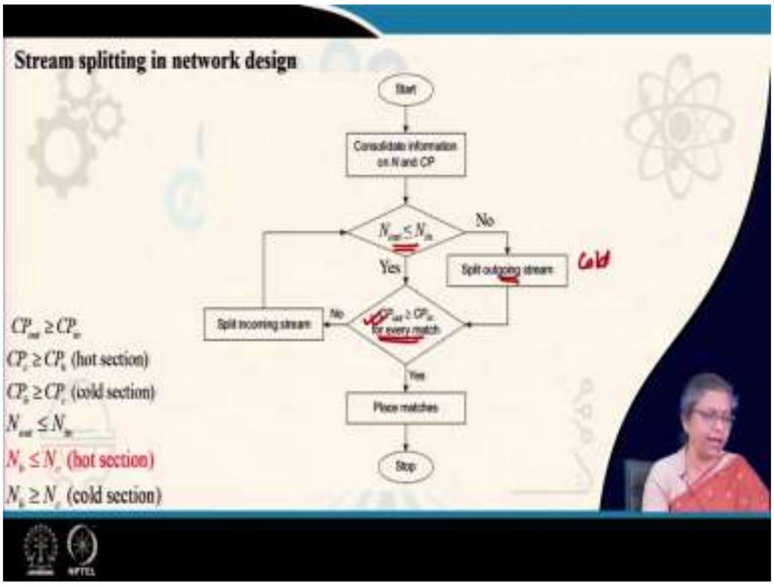

In this particular case also we think of some logic before we go ahead. The general particular criteria of stream splitting is just given in this particular flow sheet. What do we do here, first we after we collect data on N and CP we check this was not complied in our case. So, where do we go, we split, which one do we split, the outgoing stream from the hot section, what is the outgoing stream, the cold stream.

So, we split for our case, we split the cold stream after splitting we see that for every particular match we are doing whether this part is complied or not if it is complied we simply place matches. So for the problem once what happened this was complied this was complied we placed matches we went ahead. In this particular case this problem number two, this was not complied. So, we split the cold streams, split it in such a way that the for every particular stream the CP of the cold stream was greater than the CP for the hot stream either greater or equal and if this is done we go ahead.

Suppose we cannot do it then in that case what we come back again and again we stream we split the other stream this goes on till the entire match is done so therefore, in this particular way we are supposed to proceed and we are supposed to go ahead.

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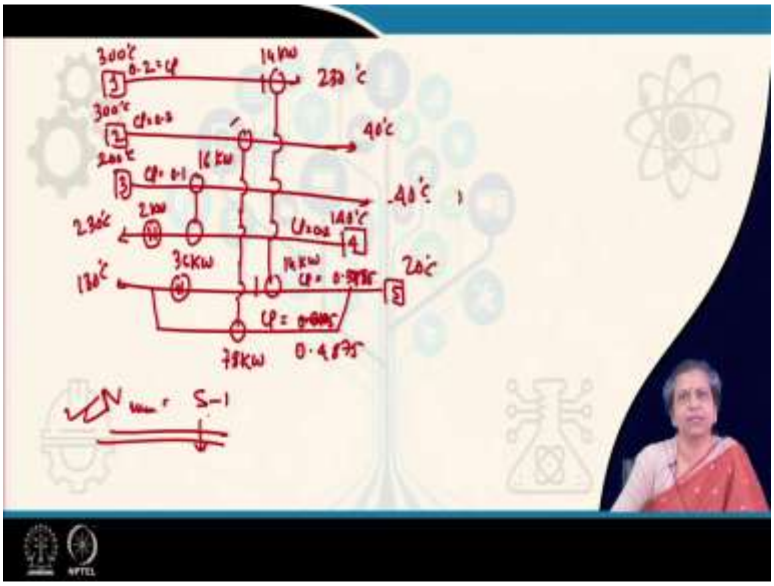

So, therefore, based on this now suppose we proceed then what do we get? We have got a stream 1 which starts from 300 degree centigrade it goes to 230 degree centigrade. CP is this another stream, it starts from 300 degree centigrade the CP equals to 0.3 it goes till more or less it goes till the pinch temperature 40 degree centigrade. Right then there is one other stream there is a stream 3 which goes from 200 degree centigrade, the CP equals to 0.1 this also goes till 40 degree centigrade the pinch temperature.

Next we have one more stream the hot the cold stream in this particular case, now this stream it starts from this is four this starts from 140 degree centigrade it comes to 230 degree centigrade. The CP equals to 0.2. Then we have got the fifth stream which starts from 20 degree centigrade and it comes till 180 degree centigrade, this is the thing.

So, before we do anything what do we do we simply match these two. This is something very simple, we have a 16 kilowatt heater here. We match it, once we match we find that in this particular case we need one other heater of a very small heater 2 kilowatt. So, therefore, the entire thing is matched in this case.

After that we start we have to match 1 and 2 with this. Now as I have told you that you can break it up in different ways just keeping in mind that the CP has to be greater than either 0.2 or 0.3, but there is one thing here which I would like to tell you suppose you split it in such a way that for one stream at least the entire heat from the hot stream can be nullified, then again we do not have need any particular heater in that particular case then it is going to be much more convenient.

If you do not consider that we are going to nullify the heat of stream 1 and stream 2, but you have to maybe you have to put a heater for both the split streams of stream 5 right. So therefore, in order to avoid that what do we do, say suppose we have put one particular heater, here in this particular case ok this heater is say 14 kilowatts, in order to do it and there is one other heater that we place here, now what I have done in this particular case is I know that for this case the total amount of heat that has to be removed is 78 kilowatts.

So, in this case I try I put 78 kilowatts here. So, that the entire heat from stream 2 is removed. So, therefore, accordingly I calculate what should be the CP here this is 0.3125 moment then this is done then in that case this sorry it is sorry it is 0.4875. So moment I divide it in such a way that the CP for this is 0.4875 naturally the CP for this case then becomes 0.3125 then in that case I find that stream 2 is completely nullified and I do not need anything extra. So, therefore, this is nullified.

So, and then naturally if this is 0.4875 the total CP is pointed this is 0.3125. So, therefore, I place another heat exchanger here. This particular heat exchanger, I think, takes up 14 kilowatts of heat in this case and I need a heater here which heater will be requiring 36 kilowatts of it. So therefore, this is the entire hot end design with that you can just combine the stream I think stream 3 or something it was there you can just combine and place a cooler, you are going to get the entire design in this particular case right. So, therefore, what did I do, I found out that the it is not complied therefore, I had broken it down into two streams.

While breaking also you have to remember that you can always split the streams just by respecting this and this criteria, but during splitting also what I thought that if I can split it in such way that at least one of the hot streams can be completely cooled by the cold stream, then in that case it becomes very convenient. I do not have to place heaters on the two if you would not have done it then there has there had to be heaters on both the streams and so, therefore, just to minimize the number of heat exchange units I have done this particular process.

Now there is one very important thing which I had forgotten to mention. For both the problems after you have done the whole thing, just find out the terminal temperatures for each heat exchanger and find out that for all the cases if the terminal temperatures; that means, the temperature here and temperature here is greater than or at least equal to delta T min, the temperature here and temperature here will be at least greater than or equal to delta T min.

I have worked it out you can do it for yourself you will find that for some particular heat exchangers the temperature difference at the exit or at the inlet is equal to delta t min for the other cases they are greater than delta T min.

So therefore, if you work it out you will find for both the problem the balance has been done in such a way that you are utilizing the minimum possible utility which you are obtained from the problem table and also from the composite curve and after that you have tried to find out you have tried to ensure the minimum number of heat exchange units also and if you find out in this particular case, if you remember n minimum was equal to s minus 1.

I had told you earlier as well try to apply this for the section before the pinch, try to apply this for the section after the pinch S will be the total number of here of the streams as well as the utilities.

So you do it you will find that for all the cases that we have done for the hot end and cold end design of problem 1, hot end and cold end design of problem 2, this is going to be satisfied. By the way for the cold end design of problem two this in that way is not satisfied, but you have to remember that this is applicable only when the entire amount of heat from any particular stream is not removed by a utility.

In this case for the cold end design the entire amount of heat is removed by the utility. So, therefore, this is not satisfied. For all other cases hot section above pinch cold section below pinch in problem 1, hot section above pinch in problem 2 this is going to be satisfied. So therefore, after you have done.

So, the basic thing is just to summarize first for a heat exchange problem you have to locate the pinch point, pinch temperature you have already delta T mean you will be deciding based on economics. Locate the pinch point, once you have located the pinch point design the hot section separately, design the cold section separately. When you are designing please keep that the three rules in mind that there will be no cross heat transfer across the pinch, no hot utility below the pinch, no hot cold utility above the pinch.

Design the two separately, for designing the hot section and the cold section represent both of them in the form of grid diagrams. Place the heat exchangers using the tick of heuristics and whatever unbalanced thing remains just compensate them by the utilities and you will find out that you if you have done it correctly then you will not need a cooler in the cold section, you will not need a heat sorry you will not need a heater in the cold section, you will not need a cooler in the hot section.

Again I repeat this was an idealized case in industries you will find that several times the situation arises that for certain compensations there has to be some cross heat cross pinch heat transfer which increases definitely the utility cost, but at the same time it might reduce the total number of exchanges, for example, suppose between two streams you find you have placed exchanger both before the pinch as well as after the pinch.

Then in that case you can combine them the two which again it brings about cross pinch heat transfer, but it reduces the number of heat transfer units. So, these things can be done, but more or less I have tried to give you a basic idea of how to perform heat exchanger network analysis using some very simplistic examples.

Thank you very much.