Process Integration
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Module - 5
Pinch Design Method for HEN Synthesis
Lecture - 4
Design for Threshold Problems

Welcome to the lecture series on Process Integration. This is module-five, lecture number four, and topic of the lecture is design for threshold problems. We have already seen pinch design methods or the rules through which a heat exchanger network can be designed. Now we demonstrate the above rules through designs of heat exchanger network. For this purpose, we have selected three different problems - one design for threshold problems, the other design for a single pinch problem, and the third design for multi pinch problems.

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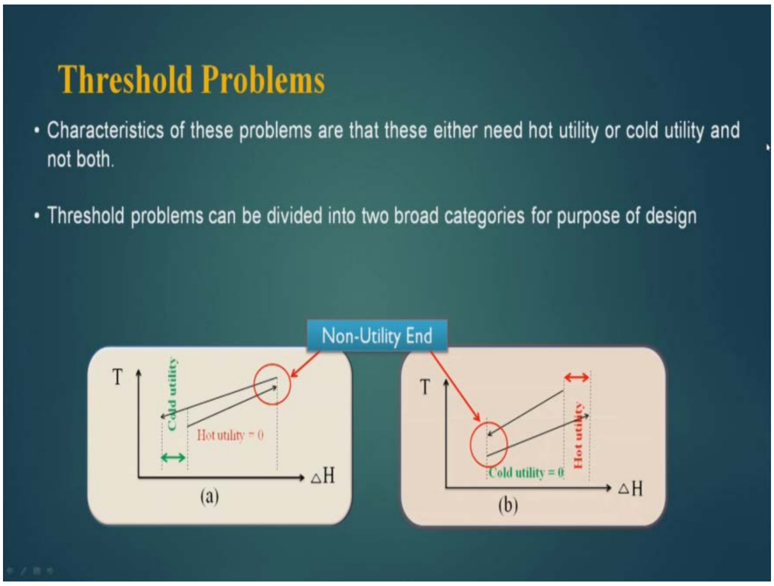

Now, let us see what is the threshold problem. Characteristics of threshold problems are that this either need hot utility or cold utility, but not both. Thresholds problem can be divided into two broad categories for the purpose of design. The first type, the closest temperature approach between the hot and cold composites is at the non-utility end and the curves diverge away from this point. Now, this shows two examples of such problems. In the first problem, this is the non-utility end, here the hot utility requirement is zero. And in the other end, which is a utility end, here there is a requirement of cold utility. Now the delta T is minimum here, but while we go away from this, the delta T increases.

Similarly, for this problem at the cold end the utility is zero, so this is called non-utility end and here there is a requirement for hot utility, because this cold stream is to be heated from this point to this point. Now the delta T minimum is at non-utility end, which is the cold utility end here, and as we go away from it the delta T is increasing. So, this is one set of problem, and it is a simple one, because delta t is less here, and then it is increasing continuously, in this also.

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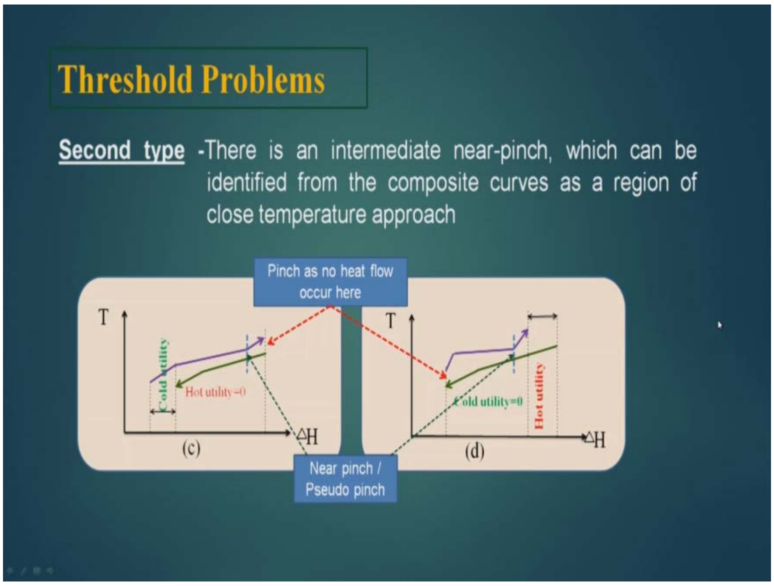

Now the second type of problem is, there is an intermediate near pinch, which can be identified from the composite curves as a reason of close temperature approach. This is the pinch area, where there is no flow of it; and this is non-utility end, and then when we go from non-utility end, we find a area here which is a near pinch area or is pseudo pinch area. And then the delta T increases and this is a area where cold utility is required. So, here it is a non-utility end, here we do not need hot utility, and the hot utility requirement is zero, but this is not the minimum temperature, here the minimum temperature is not there. When we approach, here we find a second point where there is a near pinch area or a pseudo pinch area.

Similarly, here this is the non-utility end, where the cold utility requirement is zero, but here there is a hot utility requirement, so when we go away from here, we find a zone here where the delta T is very less and this will be called a near pinch or a pseudo pinch area. So, we have seen that two type of problems can arise out of threshold problems, and we will take the example of both problems and we will design heat exchanger network for the above two problems.

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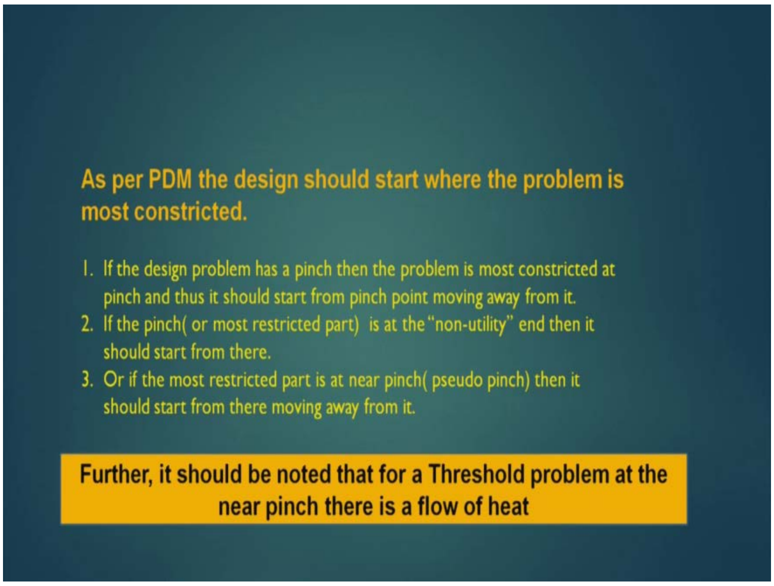

As per the PDM rules, the design should start where the problem is most constricted, this we have learnt. Now if the design problem has a pinch then the problem is most constricted at the pinch and thus it is should start from pinch point moving away from it. If the pinch - or the most restricted part, otherwise is at the non-utility end then the design should start from there and it should move away from the pinch. Or if the most restricted part is near pinch or pseudo pinch, then it should start from there moving away from it. But in this one thing we should remember that in a threshold problem at the near pinch, there is a flow of heat. So, we should not confuse with this. In ordinary pinch problems at the pinch the heat flow is zero and hence the problem is divided into two parts. Whereas in a threshold problem, it is not there; in the near pinch area, there is a flow of heat. This will be clear, when we take up the examples.

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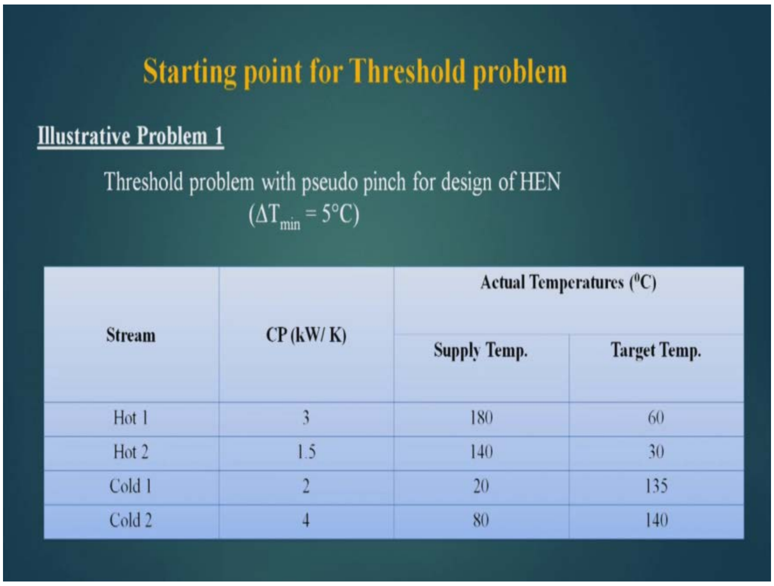

Stream	CP (kW/ K)	Actual Temperatures (°C)	
		Supply Temp.	Target Temp.
Hot 1	3	180	60
Hot 2	1.5	140	30
Cold 1	2	20	135
Cold 2	4	80	140

So, we take this problem, where there are two hot streams and two cold streams, they are CP, supply temperature and target temperatures are given, and delta T minimum is taken to be 5 degree centigrade.

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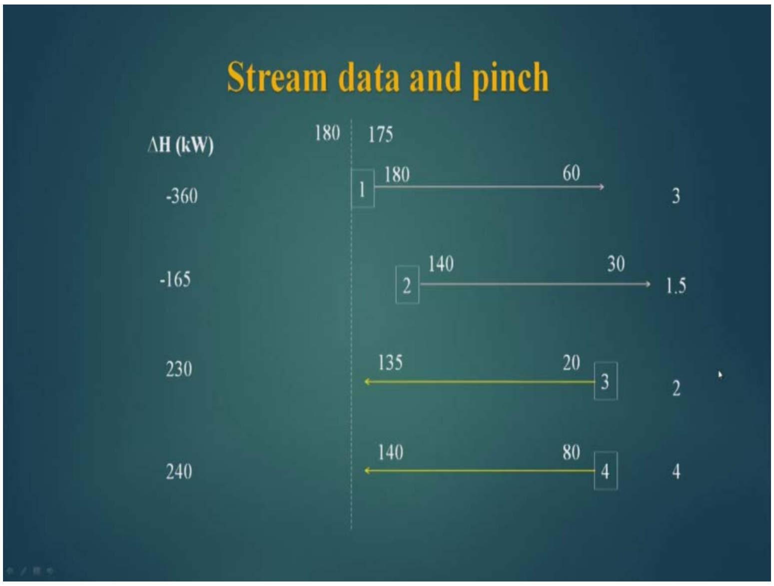

Now if you plot this stream data here, this vertical line shows process pinch. We saw all the streams are in one side, and here there is no stream.

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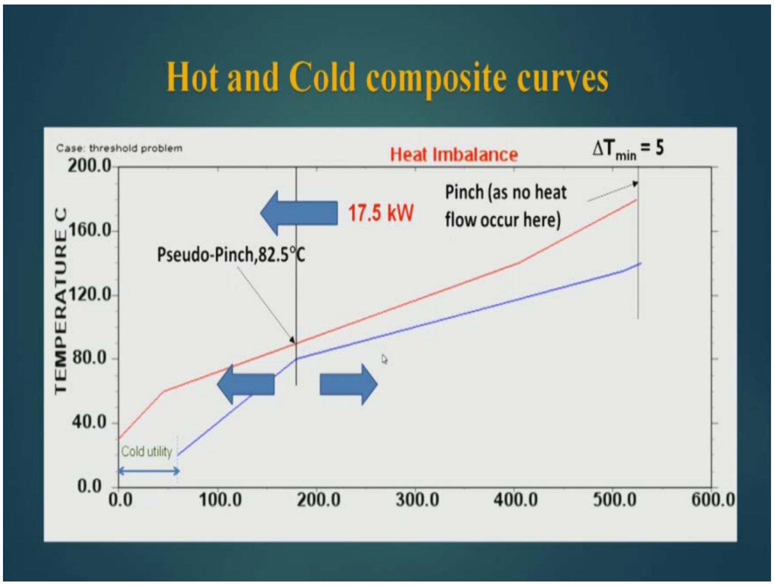

Now this shows the composite curve of the problem. Here this is hot composite curve, this is cold composite curve, and this is the pinch process pinch area, and this is the pseudo pinch. So, why process pinch here, because no heat flows here; hot utility requirement is zero, so this is a process pinch area, this is a pseudo pinch area. And the design will start from here pseudo pinch, and it will move in this direction as well as in this direction. So, I except thus for this problem, we have to design the whole problem in two parts. Now this part, which is below the pinch, but above the pseudo pinch and that is why it will be called a hot end; and this is below pseudo pinch, so this will be called a cold end. So, the rules and regulations of pinch design for hot end will be applicable to this area, and cold end will be applicable to this area.

We see that here the problem is most constraint that is delta T minimum is very less and then the delta T increases in this direction, and delta T also increases in this direction, and there is a cold utility requirement here. Now it is most interesting part is that at this pseudo pinch, some amount of heat which is we will calculate and see, it comes out to be 17.5 kilowatt is passing from hot end to cold end, which is a uncommon in a process pinch area or in a utility pinch area. But we have to remember that in a pseudo pinch, the heat transfer takes place from hot to cold.

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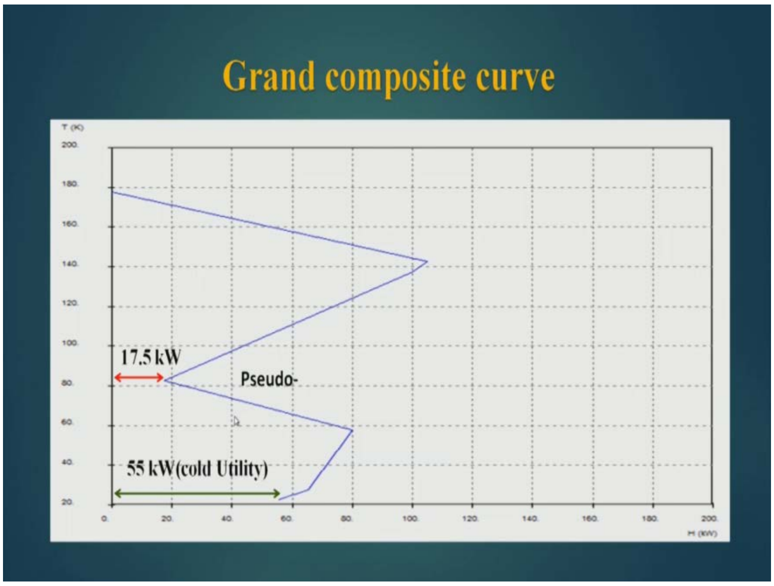

If we see the same problem in a grand composite curve, this is the amount of heat which is passing through pseudo pinch; and this heat which is coming from here, if I consider a vertical heat transfer from this hot streams is directly passing to the cold stream here below. And it is not doing any work, it is directly passing to the cold stream, and thus it is a total loss of heat. Here the cold utility requirement is 55 kilowatt, it is given by this distance, and this distance shows that the how much heat is passing through a pseudo pinch area.

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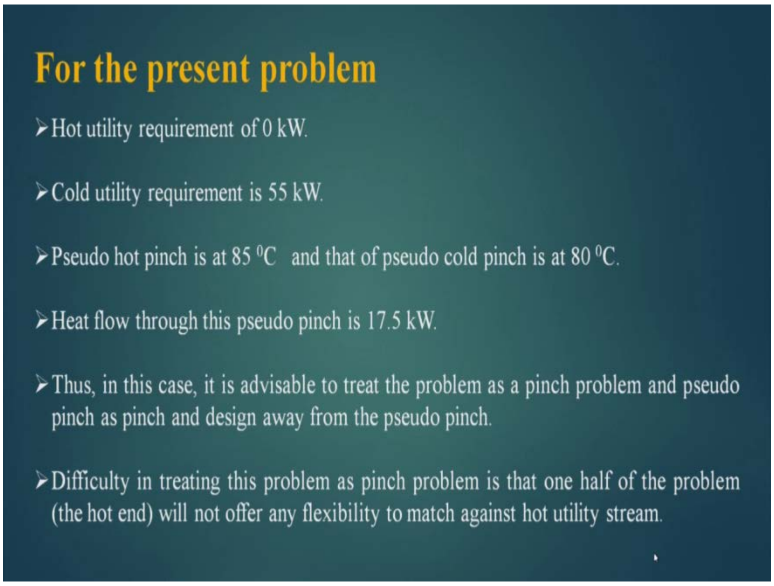

So, these are the requirements, for hot utility requirement is zero, cold utility requirement is 55 kilowatt, the hot pseudo pinch is at 85 degree centigrade, and the cold pseudo pinch is 80 degree centigrade, difference is five degree. And the heat flows through this pseudo pinch is 17.5 kilowatt, this we will calculate. Thus, in this case, it is advisable to treat the problem as a pinch and pseudo pinch as pinch, this is important. We are considering pseudo pinch as pinch, but it does not qualify the pinch completely that is why we call it pseudo pinch, because heat will be transferred through this pseudo pinch and the amount is 17.5 kilowatt for this problem. And design should be away from the pseudo pinch in both direction. Difficulty in treating this problem is as pinch problem is that one half of the problem the hot end will not offer any flexibility to match against the hot utility stream, because the hot utility stream requirement in this half is equal to zero.

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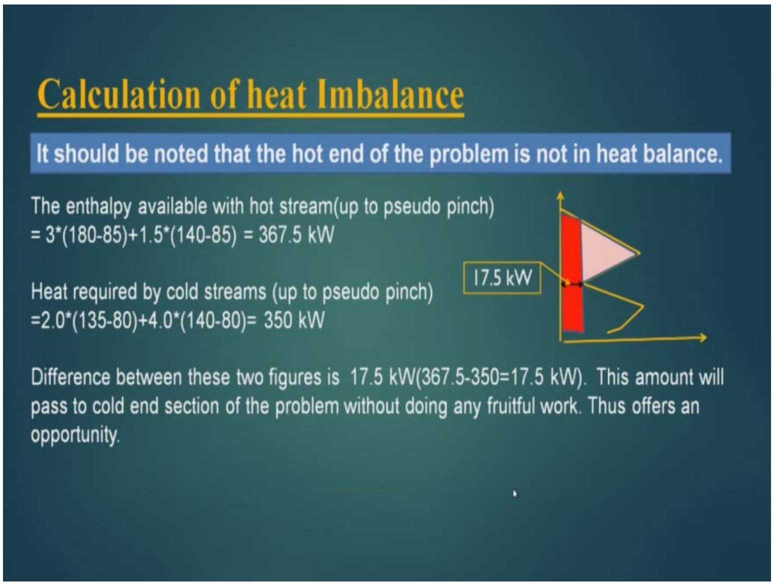

Now, the enthalpy available with the hot streams up to the pseudo pinch is 367.5, this is the hot stream number one, this is the hot stream number two, so this is 367.5 kilowatt. Similarly, the heat required up to the pseudo pinch by the cold streams, this is the first stream, this is the second cold stream, this comes out to be 350 kilowatt. So, if I compare these two or deduct from hot to the cold it comes out to be 17.5 kilowatt, so 17.5 kilowatt of heat will pass from this hot stream to the cold stream. So, this is a red area which shows it passing from here directly to the cold stream, and this amount is 17.5 kilowatt. This amount of heat will pass from hot section to the cold section without doing any fruitful work. So, I am not getting any work out of this heat flow, thus offers an opportunity to use it in this design.

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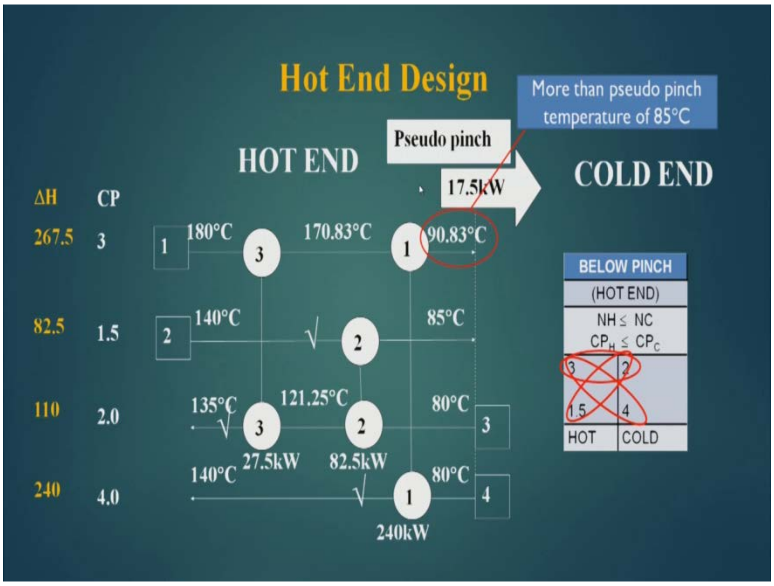

Now this is the grid diagram, and this is the pseudo pinch area. So, my design is below the pinch and above the pseudo pinch. So, this zone is below the pinch - process pinch, and above the pseudo pinch area, so we call it a hot end. And here it is written below pinch, this is below process pinch and we call it a hot end. So, the hot end rules and regulations are here that means, NH should be less than or equal to NC, this rule is satisfied at NH is equal to NC here. Now the other rule is CP H should be less than or equal to CP C. So, while I am putting match, we will see this rule is taken care of, so here we have two hot streams with 3 and 1.5; and there are two cold streams 2 and 4. So, these are hot stream, and these are cold stream. Now let us put the match. Now here this stream as 267.5 kilowatt with it, and this requires 240 kilowatt. So, based on this CP rule, if I put this match 3 to 4, this is perfectly agreeing with this rule CP C 4 is more than CP H 3, so I can put this match. And as per the take up rule, I can pass 240 kilowatt of heat energy from this stream to this stream. So, the heat exchanger number one match is correct match or acceptable match, because it obeys all the rules, and this is a pinch match. So, the rules has to be obeyed very strictly for this case. So, once I put this match, this stream is ticked off.

Now I put the second match, which is between 1.5 and 2, here also the rules are followed CP C which is 2 is more than 1.5 which is CP H. Now we see that this amount delta H with this stream is 82.5, so you can pass on the whole amount to this stream because it can take 110 kilowatt which was more than 82.5 kilowatt. So, this match is as per the CP rules, and this is also a pinch heat exchanger, and that is why this rule has to be obeyed very strictly. So, this stream is ticked off now.

I put a third match between 3 and 2. This match is not obeying CP rule, because CP H is more than CP C. And this match is for 27.5 kilowatt, and once I put this, this stream will be tick off, because from here 82.5 kilowatt as come here, it was needing another 110 kilowatt; 110 minus 82.5, this comes out to be 27.5 kilowatt. So, I have putted 27.5 kilowatt heating here from here. So, this stream is ticked off, so this is ticked off, this is ticked up and this is ticked off.

Now this should cool down up to 85 degree centigrade, but and if it cools down up to 85 degree centigrade, it will contain 285 kilowatt. But as this stream will take some heat which is equal to 17.5 kilowatt to the other side this cold end, this cannot cool down to 85 degree centigrade. So, it cools down to 90.83 degree centigrade which is a summation of this and this. So, if I add 240 to 27.5, 240 with 27.5, this comes out to be 267.5. So, it will pass only 267.5 kilowatt to this cold stream, and remaining 17.5 kilowatt will be passed to the cold end, and hence it will not cool down 85 degree centigrade here, it will cool down to 90.83 degree centigrade. So, this has to be observed that this is more than the pseudo pinch temperature of 85 degree centigrade. So, 17.5 kilo watt will pass from this hot end to cold end.

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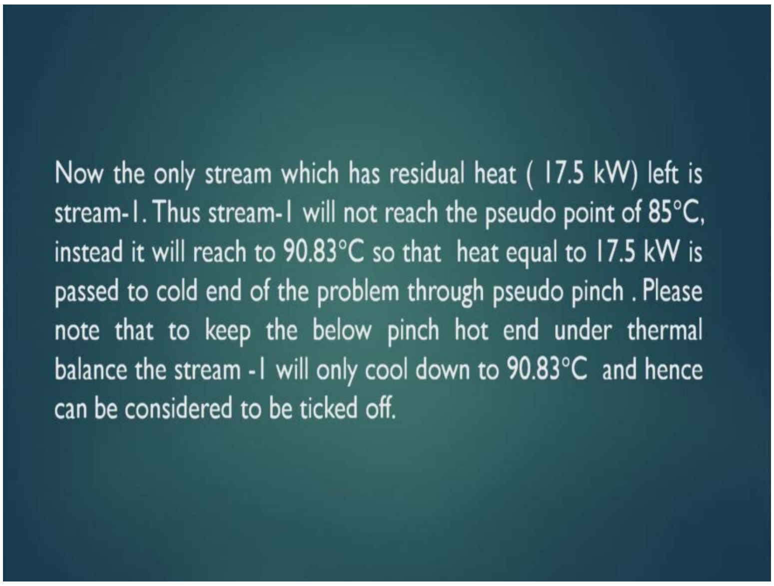

Now the only stream, which has residual heat 17.5 kilowatt left is stream-I. Thus stream-I will not reach the pseudo point of 80 degree centigrade, instead it will reach up to 90.83 degree centigrade, so that heat equal to 17.5 kilowatt is passed to cold end of the problem through pseudo pinch. Please note that to keep the below pinch hot end under thermal balance stream-I will only cool down to 90.83 degree centigrade, and hence can be considered to be ticked off. So, in the last slide we have seen that all the stream have been ticked off. So, our design of the hot end of this problem is complete.

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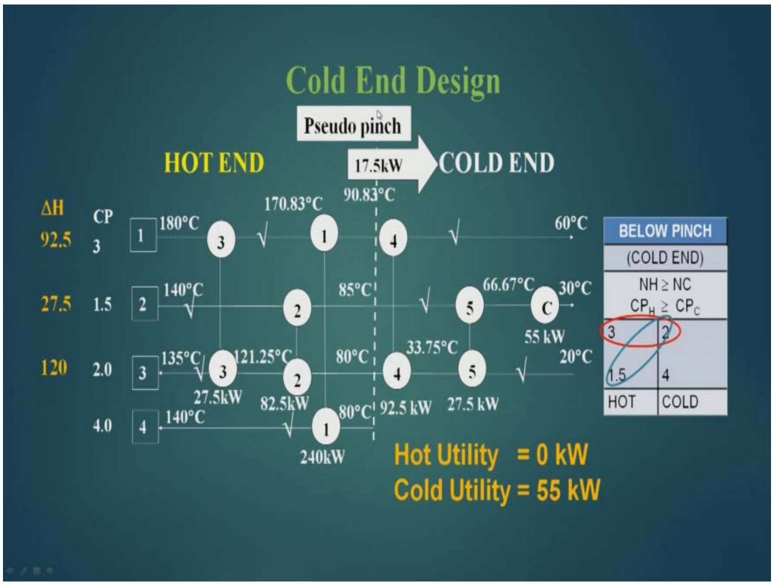

Now we have to design for the cold end. So, the hot end is complete. And this is the pseudo pinch 17.5 kilowatt is passing to the cold end, so we have to design this cold end. So, I have a table here CP table, so this is below pinch design, but this is cold end; that means, it is below the pseudo pinch also. And the rules are this which are the inverse of the reverse of the rules of the hot end design. Now this 7.5 kilowatt which is passed here, has to pass to the cold routes, but here I have only one cold and two hot, and then I have to use a cold utility. So, first we put a match between the CP 3 and CP 2.0, this match. And here CP H is greater than CP C, so this rule is valid. Here there are two hot streams and one cold streams and hence this rule is also valid.

So, once I place this may this stream is ticked off, why, because now this stream has got a delta H of 92.5 kilowatt including this 17.5 kilowatt, so this is 92.5 kilowatt, so this is ticked off. And this you can calculate, so this comes down from 690.83 minus 60 into 3 which is almost equal to 92.5 kilowatt, so this stream is ticked off. Now I put a second heat exchanger between this 2.0 and 1.5. So, this is 2.0 and 1.5, this match is does not obey the CP rules; this match does not obeys the CP rules, whereas this match obeyed this CP rule. This is a pinch heat exchanger, so it has to obey this CP rule very strictly. But this is a non-pitch heat exchanger, so CP rules can be somewhat diluted for this; unless otherwise, we cannot put a match, but we have to see that this does not violate the delta T minimum criteria.

So, here delta T is 66.67 and this is 20, so this not violating. So, this is this stream is ticked off, and then we are putting a cooler here, which is 55 kilowatt which was the required cold utility demand. Here also we can see that this temperature is 33.75, and this temperature is 85. So, here the delta T minimum criteria is not violated, here the delta T minimum criteria is not violated. So, this match, which is 2 and 1.5 match which is a heat exchanger number five is all right. And being a non-pinch heat exchanger it did not violated the delta T minimum criteria; otherwise it would have violated, it would have been the pinch heat exchanger.

Now from this 66.67 degree centigrade to 30 degree centigrade, this has to be cold down by a cold water, which is a cold utility, and its will be 55.0 kilowatt which was the requirement of our cold utility. And all the streams are now ticked off and hence this design cold end design is now complete. So, the hot utility requirement for the design is zero kilowatt, the cold utility requirement is 55 kilowatt, this is what we have we can observe from the PTA, and hence the design has matched with the targeted value. So, this is the complete design of the heat exchanger network for the problem where there is a pseudo pinch.

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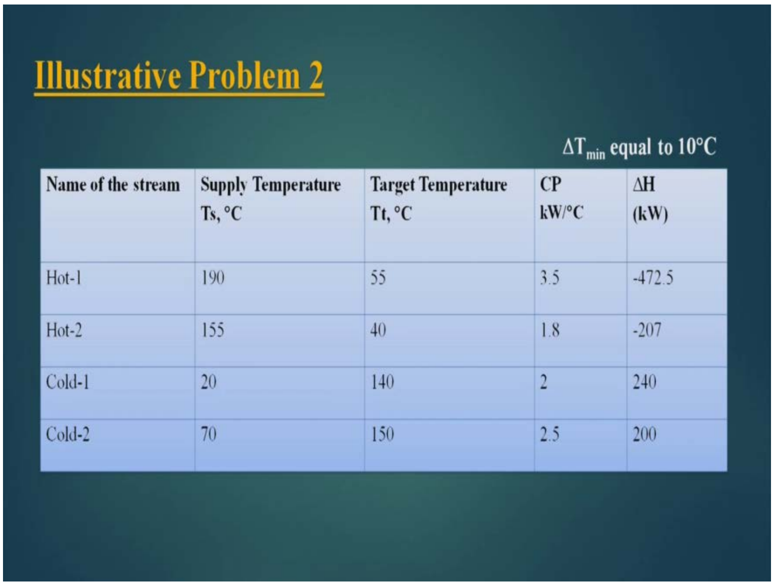

Name of the stream	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH (kW)
Hot-1	190	55	3.5	-472.5
Hot-2	155	40	1.8	-207
Cold-1	20	140	2	240
Cold-2	70	150	2.5	200

Now we have seen one part that is if the problem has got pseudo pinch, how to handle it. Now you see a second problem where the problem does not have a pseudo pinch, the delta T minimum is at one end, which is not utility end, and then it increases. So, if such a problem is there then how to handle it. So, this is our problem, where there are two hot stream and two cold stream, delta T minimum is 10 degree centigrade.

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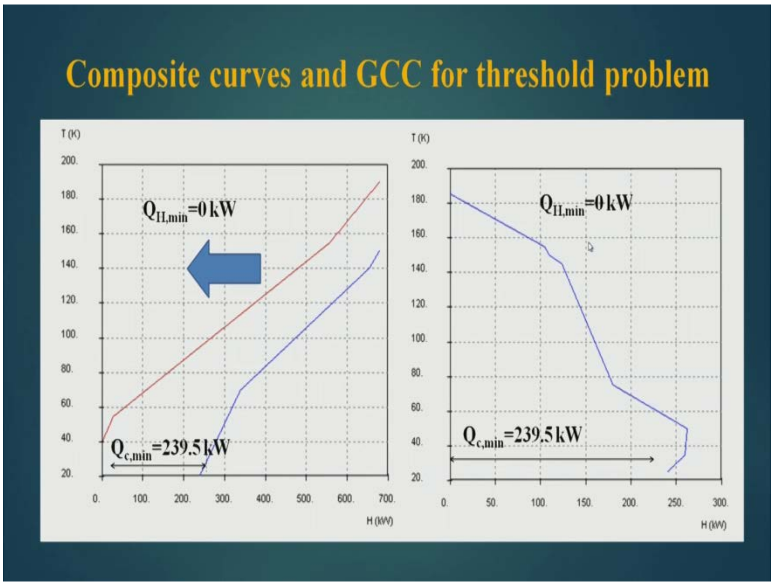

And the composite curves for this is this; that means, this is the non-utility end, where hot utility requirement is zero, but there are some cold utility requirement here. So, hot utility requirement is 0, cold utility requirement is 239.5 kilowatt. So, the design will start from here, and it will move in this direction, because here the delta T is opening up. And this is the minimum delta T available, when we go move from in this direction the delta T is increasing. This is the GCC of the threshold problem, we see here there is no hot utility requirement, it touches this y-axis, but there is a cold utility requirement here 239.5 degree centigrade. So, how to design a heat exchanger network for this problem?

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Now this is the stream data; here are the hot end, there is nothing no streams, have the cold end all streams falls. So, in a threshold problem, we always face such type of problems. It is almost half of the ordinary pinch problems. So, here will be designing below pinch, below process pinch area, and that is why it will be a cold end. And if it is cold end, then my CP table the rules will be for cold end design. Here we see that NH and NC both are here, there are two end two streams, but it is not solving our purpose that is why will have to split a stream. So, if I split a hot stream then I have to also split a cold stream to make the number equal. And this splitting is done, because it will not have that Cp, it will not conform to the CP H rules or matches and that is why you have to go for this.

So, we are splitting a hot stream and we are splitting a cold streams. So, the first match, we are putting between 3.004 and 2.5. So, this rule is valid for this 3.004 and 2.5; CP H is more than CP C. This stream has got 200 kilowatt of energy, it can take. And this part that is having 3.004 CP can give you 200 kilowatt, this you can calculate 190. Now the second heat exchanger, which we will be putting is with this and this; that means, 1.8 to 1.725, this is 1.8 CP of this stream and this is 1.725. So, as per this rule, this is perfectly ok, and we can put a match of 207 kilowatt, and we can tick off this stream.

Then we can put a third match between 0.495 and 0.278, this is also according to this CP rule. So, this match is 33 kilowatt, and this along with this cooler 239.5 kilowatt ticked off this. Now you can calculate the temperatures, this is 140 degree centigrade, it cools down to 20 degree centigrade, when I pass 33 kilowatt energy, and this from 140 degree centigrade to 20 degree centigrade cools up, when it passes 207 kilowatt of energy. This you can calculate 140 minus 20 into 1.725 comes out to be 207. So, 140 minus 20 into the CP of this stream which is 1.725 comes out to be 207, and that is why this is ticked off. Similarly, this is 190, so if you do this 190 minus 123.43 into 3.004, this will be around 200 kilowatt. So, this part of the stream is ticked off. Similarly, 190 minus 123.43 equal to this into 0.495 comes out to be about 33 here. So, this part of the energy with this part of the hot stream is about 33 kilowatt, it passes to the here, and this part has got 200 kilowatt it pass to here. So, this requires 200 kilowatt, this is ticked off. And the heat which has with this stream is 200, so this 207 plus 33, so it comes out to be 240 kilowatt.

So, 240 kilowatt heat is pass to these two streams and that is why it is ticked off. So, this is ticked off, this is ticked off and this is ticked off. So, here it is 123.43 degree centigrade, this has to be cool down to 55 degree centigrade. So, it requires a cooler. So, we place a cooler, which has got a capacity of 239.5 kilowatt. Now all the with this, this is ticked off, so all the streams are ticked off, and hence this and the cold utility requirement was 239.5 kilowatt, and this cooler is taking 239.5 kilowatt. So, it is this design is complete and according to the targeted value of 239.5 kilowatt of cold utility. So, this completes these design.

Thank you.