Heat Exchangers: Fundamentals and Design Analysis
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Lecture – 63
Heat exchanger network

Hello, participants. So, we are back again in our course on heat exchanger; Heat Exchangers, Fundamentals and Design Analysis. In that we are working on a topic called Heat Exchanger Network Analysis and as I have told that we will do it by pinch technique. Of course, I have not introduced what is pinch technique we I have told earlier that we will try to learn this technique or heat exchanger network analysis by pinch technique through a problem.

So, this problem has already been introduced in the last class let us go to the problem.

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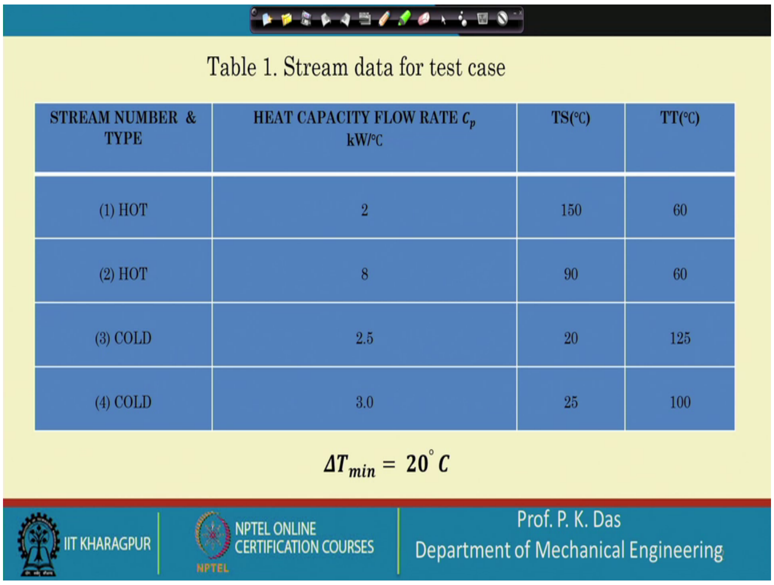
Table 1. Stream data for test case

STREAM NUMBER & TYPE	HEAT CAPACITY FLOW RATE c_p kW/°C	TS(°C)	TT(°C)
(1) HOT	2	150	60
(2) HOT	8	90	60
(3) COLD	2.5	20	125
(4) COLD	3.0	25	100

$\Delta T_{min} = 20^{\circ} C$

So, the problem it has got two hot streams the heat capacity flow rate capital C it should not be C it should be capital C it should not be C p it should be capital C kilowatt per degree Celsius that is for this two hot streams 2 and 8. Then temperatures are given one is from 156 degree Celsius, another is getting cooled from 90 degree to 60 degree Celsius. Then there are two cold stream their heat capacity rates are given and at the same time the temperatures are al given that is one is from 20 to 125 degree Celsius and another is getting heated from 25 degree Celsius to 100 degree Celsius.

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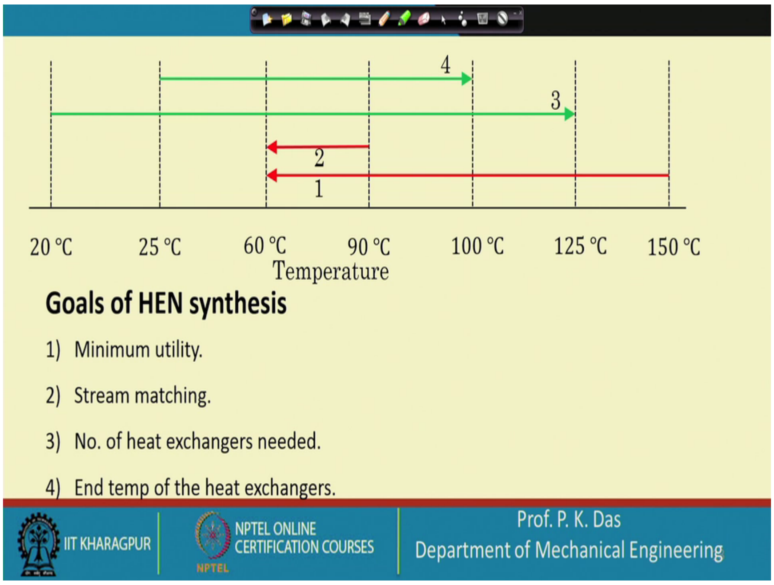

In our last class I have shown this one also I do not like to elaborate much.

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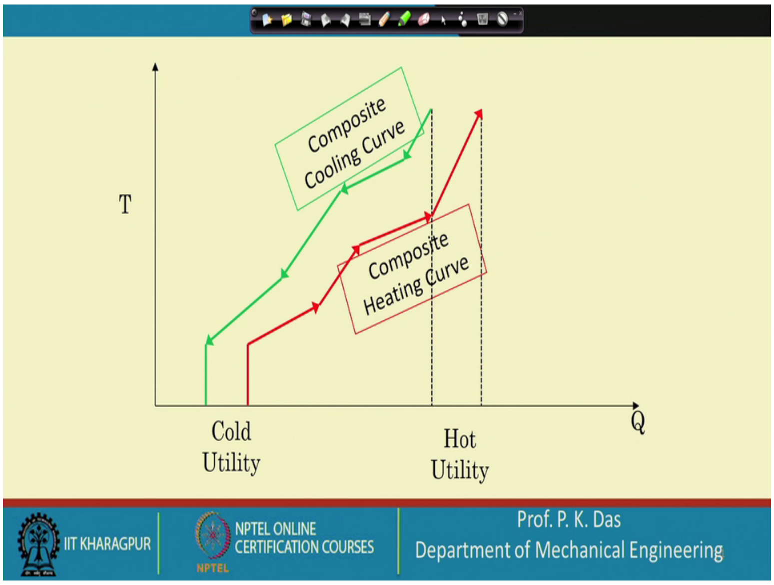

And, then this composite curve has been mentioned. So, this is just for continuity. Now, let us proceed with this problem. The problem will be solved by a method which is called problem table technique or problem table method.

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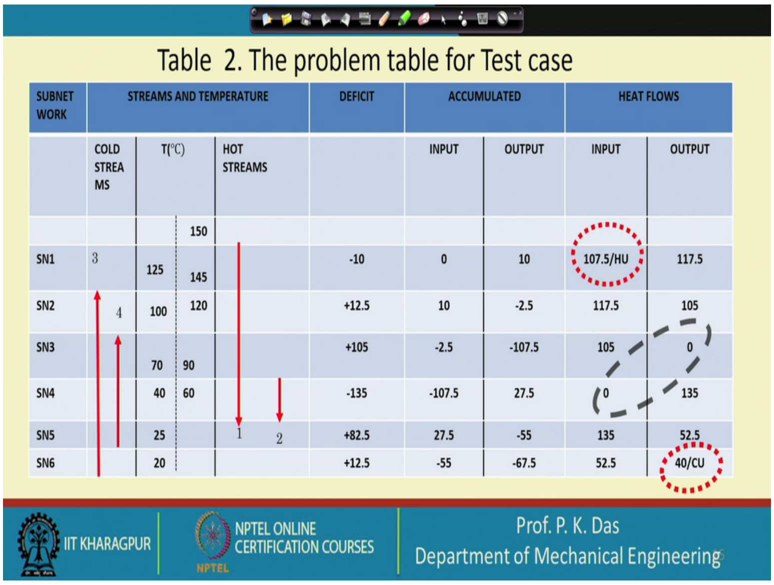

So, this is our problem table for the test case which we have taken. So, you see in this table there are number of number of columns; columns are very important and then of course, there are number of rows also. Now, on the left hand side of the table, this is the left hand side of the table we have got cold streams. You see there are two cold stream, one cold stream is from 20 degree to 125 degree Celsius. So, this is one cold stream and another cold stream is from 25 degree Celsius to your 90 degree Celsius. So, that is also there we are having, ok.

So, these two cold streams we can think of and let me see whether it is ninety degree or hundred degree Celsius let us go back to the problem definition. So, one cold stream is 20 to 125 another is 25 to 125 one 100 sorry 100. So, this is what has been shown that one is 20 to 125 this is 20 and this is 125 and then another one is 25 to 100, and respective heat capacity rates have been have to be considered also what are the heat capacity rate of these that also has to be considered.

Then there are two hot streams one hot stream is 150 degree Celsius to your this is 60 degree Celsius and another is from 90 degree Celsius to 60 degree Celsius. So, these two streams are also shown, 150 to 60 and then from 90 to 60. So, you can understand that this side we have got the temperature of the hot streams and this side we have got the temperature of the cold streams.

Now, then at least four strategic temperatures which are fixed in this particular problem we have got other temperatures we will get some sort of a guess value without violating the problem statement. Let us say 125 is the cold stream temperature if the heat transfer is very a efficient. So, here the hot stream temperature should be at least 20 degree Celsius higher than 125 degree Celsius because the 20 degree Celsius is the pinch temperature for this particular problem. So, here we have written 145, we do not know this temperature.

Similarly, the cold stream temperature here is 100 degree. So, the corresponding hot steam temperature could be your 120 degree here the hot stream temperature is 90 degree. So, corresponding cold steam temperature could be 70 degree in ideal case. Here it is 60 degree corresponding cold stream temperature could be 40 degree and beyond this there is no hot stream. So, only cold stream is there. So, this is how we will get our temperature distribution for different stream. So, you see now we can have different temperature zone and in each temperature zone we can think that as if we are having a sub network.

We are considering a total network of heat exchangers, but for a come a small temperature range we can have a sub network. Like let us say here the hot stream hot stream number one that starts from 150 degree and it ends at 145 degree somewhere in between of course, after that also it is getting cooled. So, one interval of temperature we can get the in which there is only one stream one hot stream 150 degree to 145 degree so, that becomes your sub network 1.

Similarly, we can get sub network 2 in that we have got two streams, we can get sub network 3 in which we have got three streams, we can get sub network 4 in which we have got four streams, again sub network 5 in which we have got two streams and sub network 6 in which we have got only one stream and temperature ranges.

Now, in sub network 1, what is happening? The hot stream is getting cooled from 150 degree to 145 degree. There is 5 degree Celsius of temperature drop maximum temperature drop could be 5 degree Celsius. It could be less even, but maximum could be 5 degree Celsius and what is the heat capacity rate of this hot stream? Let us go to some previous slide. Heat capacity rate of the hot stream is given here for the first hot hot stream which is 1, the heat capacity rate is to 2, 2 kilowatt per degree Celsius.

So, if we go back to our problem table then here there is a 10 degree temperature drop and heat capacity rate is 2. So, here sorry, here there is a 5 degree temperature drop 150 minus 145 so, 5 degree and there is a heat capacity rate of 2. So, minus 5 into 2 so, deficit is equal to minus 10. This is not getting an input, but there is a deficit of minus 10 and what is this deficit this definitely is going to the next sub network.

So, for this sub network, sub network 1 input is 0, from outside I am not supplying any heat from there is no other sub network at the top of it. So, input is 0 and it is giving to the lower sub network a heat of 10 kilowatt. So, this is 10 output is 10 we can do similar calculation. So, deficit here will be 12.5 plus 12.5, input is 10, what was the output of the previous network this is the input of the this network. Output of sub network 1 is the input of sub network 2 and then the deficit we have to consider; that means, your input minus the deficit. So, that will give you minus 2.5 that will be the output.

Minus 2.5 will be the input of sub network 3 and again by going by the same kind of logic you can do this problem all the data are given. So, output will be minus 107.5 minus 107.5 will be input to sub network 4 and the output will be 27.5. 27.5 will be input to sub network 5 and the output will be 55 minus 55. Again, minus 55 will be input to last sub network that is sub network 6 and we will have an output of minus 67.5.

So, now each and every sub network we have got the value. We have got the value like the first sub network will have 0 input and it will have a output of 10, second sub network will have a output of 10 sorry input of 10 output of minus 2.5. Third sub network will have a an input of minus 2.5 output of 107.5 and then the next sub network that is sub network 5, 4 will have an input of minus 107.5 and output of 27.5. Sub network 5 will have an input of 27.5 output of minus 55 last sub network will have an input of minus 55 output of minus 67.5.

Now, next step, again you see that we have put input and output. Now, what we like to do that we do not want to make any input as negative, ok. So, we want to do it in such a way, so that no input is negative. Input negative means what is the meaning of input is negative? Input is coming from a sub network at the top to the sub network at the bottom and if we see the networks they are different temperature ranges; that means, input is the energy which is coming from a sub network of higher temperature to a sub network of lower temperature. Heat flow from higher temperature to a lower temperature and we can never make it negative, at best we can make it 0. But, we can never make it negative that is the violation of second law of thermodynamics.

As I have told heat exchanger network is based on second law of thermodynamics so, here we have to keep that in mind that it is based on second law of thermodynamics we can never allow heat to flow from a lower temperature to a higher temperature or always we should see that heat is flowing from higher temperature to lower temperature or at least there is no heat flow from high temperature to lower temperature, sub networks as like that.

So, to do this thing what we have to do the maximum negative input we can see 107.5, so, what we do that here at the beginning we add plus 107.5. So, if I add it 107.5 then output will be 107.5 plus 10; that means, 117.5 and the same way we will proceed some where we will get output is equal to 0; that means, no energy is flowing from a higher sub network to a lower sub network. As output is 0 for let us say sub network 3, then the input to sub network 4 that will also become 0 and this is the pinch point of the heat exchanger network. This is a very strategic very important point this is called the pinch point of the heat exchanger network.

And, once we get the pinch point then it follows automatically and all the input quantities are positive. If all the input quantities are positive we will get all the output quantities are also positive and or at least 0. Inputs are positive or 0 outputs are also positive or 0. Then what we have given at the input as 107.5, this is nothing, but from outside we have pumped certain amount of energy. So, what is this is nothing, but your hot utility. So, hot utility we have to supply 107.5 whatever you make it may be kilowatt, so, that is the amount of hot utility we have to supply.

And, then at the end of this heat exchanger network; that means, at the sixth sub network what we will find that there is a output of 40 kilo watt. So, what is that? So, this is supplied to something, this has to be supplied to something because I have to maintain all the temperatures etcetera. So, what it could be done that, this could be supplied to some cold utility. So, basically 107.5 is the heating requirement of the heat exchanger network and 40 or 40 kilo watt is the cooling requirement of the heat exchanger network and in between there is a pinch point, ok.

So, pinch point we are getting two temperatures one is 70 and 90; that means, at the pinch point my temperature will be hot stream side temperature will be 90 and cold stream side temperature will be 70. Exactly there is 20 degree Celsius of temperature difference; this is the pinch tip pinch point. Here the heat exchanger network or heat exchanger is most efficient because heat transfer is taking place at the minimum temperature difference. Everywhere else we will have some sort of temperature difference which is more than 20 degree Celsius. Up to this if you have understood then probably you have understood the half of the problem. Let me give some sort of.

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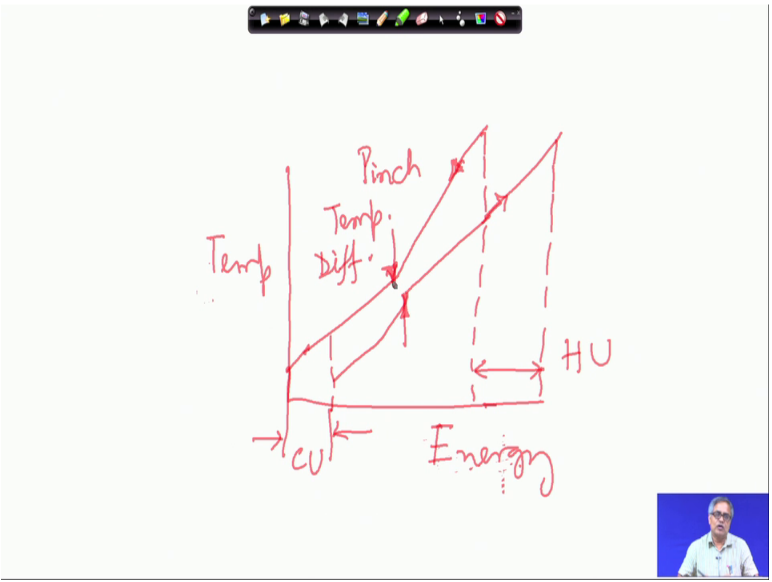

So, basically if we see the let us say this is the plane one side is energy and another side is your there could be. So, basically my hot stream is ending over here. So, this is your hot utility cold streams are being heated. So, this is your hot utility cold streams are ending over here. So, this is your cold utility, this is our energy then it becomes cold utility it becomes hot utility and this side it is temperature. So, this becomes your pinch temperature difference.

And, in the present problem this is your 20 degree Celsius. So, this is your cold utility here the hot stream is to be cooled hot stream is getting cooled partially with the help of cold stream, but entire cooling may not be possible. So, this is where the hot stream is getting cooled, this is where cold stream is being heated and this is the pinch point where we are having your minimum amount of temperature difference between the hot stream and the cold stream. We will explain it once again.

So, if you have up understood the problem table method so, let us go to let us go to the next slide what we have got here.

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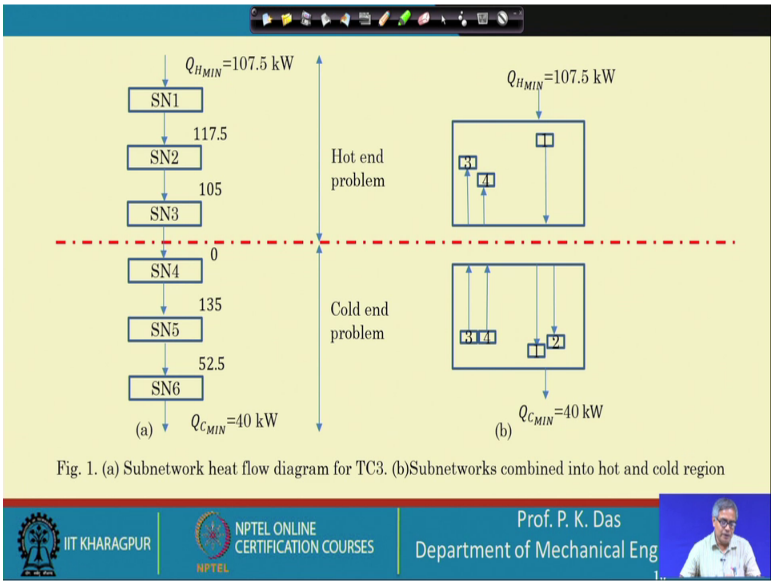

That subnetwork 1, subnetwork 2, subnetwork 3 that is above the pinch point, the redline is the pinch point, ok. So, this is the redline, this is your pinch point subnetwork 4, subnetwork 5 and subnetwork 6 is below the pinch point and here from subnetwork 1 energy is coming to subnetwork 2, from subnetwork 2 it is coming to subnetwork 3, but from subnetwork 3 to subnetwork 4, zero amount of energy is flowing. Subnetwork 4 to 5 some amount of energy is coming, subnetwork 5 to subnetwork 6 some amount of energy is coming and we can see how much energy is coming. At the top we have given 107.5 kilo watt that is the hot utility, at the bottom we are extracting 40 kilowatt that is the gold utility and we have got zero heat exchange at this point.

So, these we call it the hot end of the problem, this we call as cold end of the problem and if we see the hot stream and cold stream so, they can be shown like this. So, this is the hot end problem, this is the cold end problem. So, subnetwork heat flow diagram for this particular problem this is the problem number and subnetwork combined into hot and cold region. So, hot and cold region we can see.

So, you see pinch point then, what does it do? Pinch point then divides the problem into two problems. Two problems are now independent because no way they are connected; one is not one heat exchange one part of the heat exchanger network is not transferring heat to the other part of the heat exchanger network. So, they are not connected.

So, pinch point divides it into two different problems. This is a very important this is very profound kind of observation that by the pinch point we are having two different heat exchanger network, one is at the top which we call hot end of the problem and another is at the bottom which we call the cold end of the problem and now we can solve them independently. We can have independent solution without bothering what is happening in the cold end we can have the solution of hot end and without bothering what is happening at the at the hot end we can have the solution of the cold end.

Let us say hot end we are having two solutions that is possible we will discuss it and cold end we are having two solution hot end solution let us call it A, B and cold end we are having two solution let us call it C and D. So, what I can do I can join any hot end solution to any cold end solution. So, my total solution could be AD or my total solution could be BC or my total solution could be AC, ok. So, this is how to exam[ple]- to give example that we can have independent solution of the hot end and cold end I have told this this has to be kept in mind this is a very important aspect this is a very important aspect of pinch analysis, alright. So, let us go to the next slide.

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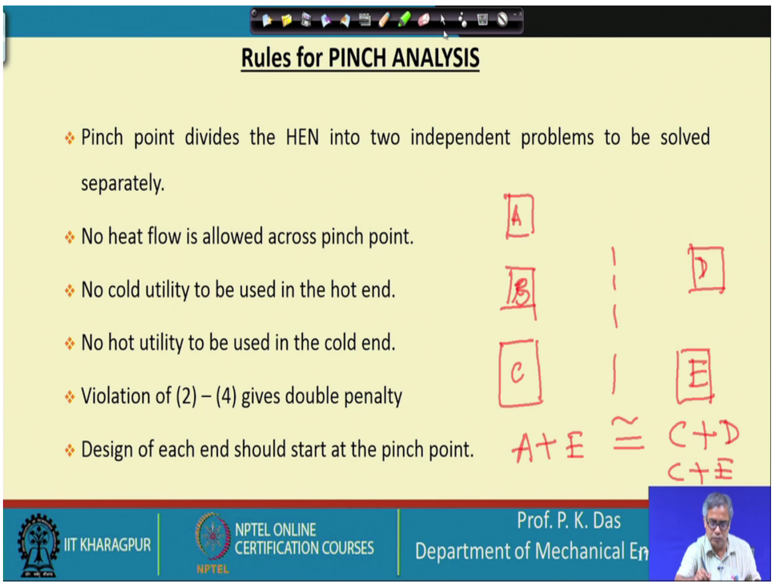

So, rule of pinch analysis. Pinch point divides the HEN – Heat Exchanger Network into two independent problems to be solved separately just now whatever I have told and explained. So, let us say this is my pinch point and I have got A B and C three different solution of the hot end and then I can have let us say D and E 2 different solution of the cold end. So, theoretically at least A plus E will be equivalent to your C plus D or C plus E, ok. So, this is what I wanted to make you understand that independently I can get the solution and I can combine the solution also independently, ok. So, this is one very important aspect of very important aspect of pinch analysis.

No heat flow is allowed across the pinch point. This is a very very important thing, that once we identify the pinch point by mistake by wrong design, by our some sort of fancy design we should not allow any heat to be transferred from one side of the pinch to the other side.

No cold utility to be used in the hot end. So, we have got one hot solution, we have got one cold solution or rather hot network hot end of the network and cold end of the network. So, no hot utility, no cold utility is to be used in the hot end similarly, no hot utility is to be used in the cold end.

So, three rules we have got; first rule is that no heat flow is allowed across the pinch point and then no cold utility is to be used in the hot end and no hot utility is to be used in the cold end and violation of 2 to 4 gives double penalty or results in double penalty. Let me explain it little bit for that what we will do let us go to I think I will sorry, I will go to this solution problem table method. Here what we have got we have got the pinch point, alright.

So, here we have got the pinch point. Now, what I try to do so, in the pinch point you see that I try to send some heat across the pinch point how I can do that let us do one thing. At the top at the hot end what I have done I have send or I have added 107.5 hot utility. So, instead of that let us add there 1010 hot utility. So, something more if I do this you will go on adding this and you will not get 0 over here, you will get some positive value. That means, this is not violating second law because from upper subnetwork only energy is coming to the lower subnetwork.

So, this is not violating second law of thermodynamics, but what we are getting we are getting some heat flow across the pinch point. Our pinch point was 20 degree Celsius based on that 20 degree Celsius we have got a pinch point at hot fluid temperature of ninety degree and cold fluid temperature of 70 degree. So, here we will find put 107 sorry, instead of 107 put 1010 you will get some heat flow. How much heat flow? 1010 minus 107.5 so, that will be 0.5, 2.5 I believe. So, 2.5 kilo watt of heat flow you will get across the pinch point.

And, ultimately what you will get? Your cold utility that will increase to 42.5 kilo watt, so, basically then you are getting a double penalty how you are getting a double penalty? Instead of 107.5 kilo watt of hot utility, you are using 1010 kilowatt of hot utility more hot utility you are using 2.5 kilo watt more hot utility you are using and instead of 40 kilo watt of cold utility you are using 42.5 cold kilowatt of cold utility. So, more cold utility you are using. So, there are two penalties one in the terms of hot utility and once in the terms of cold utility. So, this is called a double penalty and we should not have heat transfer across the pinch point. So, this is very important.

Let us quickly go back to our ha here. So, violation of 2 to 4 gives double penalty. So, this has to be avoided and then design of each end should start at the pinch point this is also I have told or I do not know whether I have told it or not, but it is very important I do not recall whether I have told it or not, but this is very important that it has to be kept in mind design of each ends should start at the pinch point. So, this few information few message I should say they are not only information they are very important rules, we have to keep it in mind. Pinch point divides the heat exchanger network into two independent problem. This problems can be solved and should be solved independently.

And, while solving this problem we should start from the pinch point and go towards either towards the hot end or towards the cold end. So, this is one message. Second message is low heat flow should be there across the pinch point, third message is low cold utility should be used at the hot end. Fourth message is no hot utility is to be used at the cold end. So, this these are the thing you have to keep it in mind. Well, we are at a very interesting point of heat exchanger network analysis. Thank you for your patience and we will proceed with the same problem in the coming in the coming lecture.

Thank you.