Energy Conservation and Waste Heat Recovery
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Lecture - 35
Heat Exchanger Network (HEN) (Contd.)

Hello every one, we were discussing the synthesis of heat exchanger network and as I had mentioned that we will follow the reference the pinch design method for heat exchanger network by Linnhoff and Hindmarsh the reference is given.

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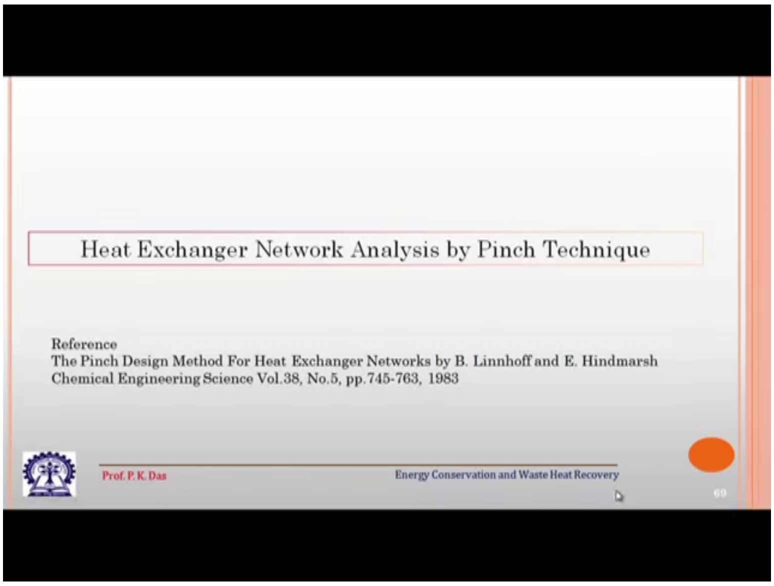

So, I have introduced the topic now what I like to do we will take up a problem and with the help of a problem small problem, we will try to see how heat exchanger network analysis or synthesis can be done using pinch technique.

So, this is basically pinch technique, there are other techniques which we will not be able to discuss because that is beyond the scope of this particular subject.

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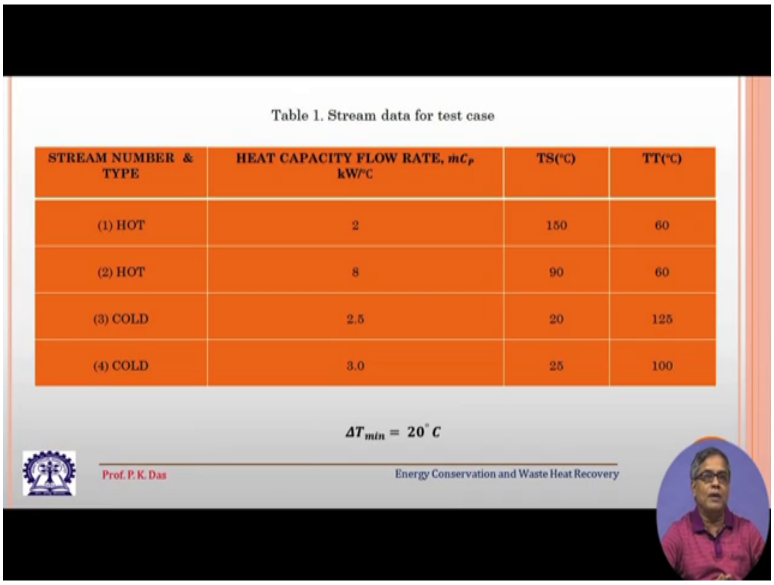

So, this is the problem which we have taken and it is again taken from the same reference which I have given at the beginning.

So, you can see there are 2 hot streams a TS denotes the target, sorry, supply temperature; the temperature with which the hot stream enters the plant and or it enters the heat exchanger network and that denotes the target temperature to which temperature the hot steam is to be cooled, there is another information which is actually m dot cp and appropriate unit. So, for the 2 hot stream 1 is 2 and another is 8. So, this is heat capacity rate.

Similarly, the informations are available for the cold stream. So, cold stream we will start with a low supply temperature and it will end up with some sort of a high target temperature because this stream is to be heated.

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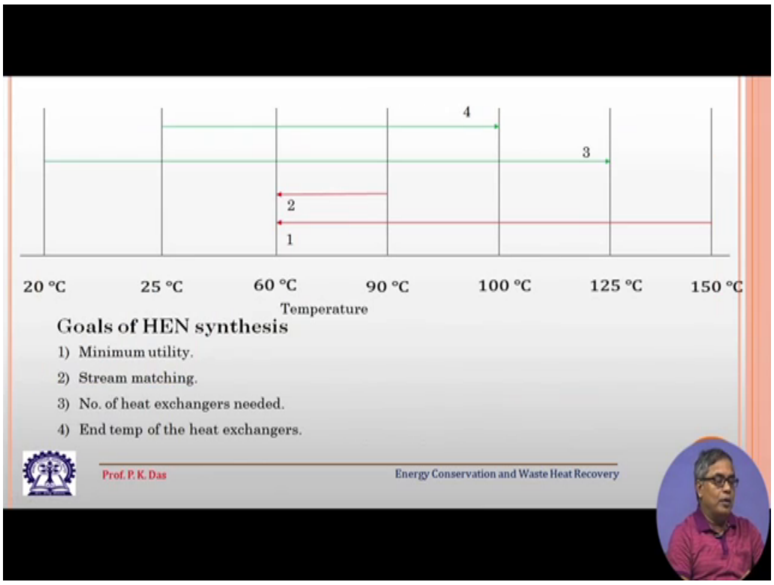

Now, graphically if I want to show the four streams in the on a on a temperatures plane it is like this the hot streams.

One hot stream is starting from here and ending here another hot stream is starting from here and ending here there are 2 cold stream, one starts from here end here and the second one starts at 20 degree Celsius and end at 125 degree Celsius. So, you can see that the supply and target temperatures are different and already I have told that the heat capacity rate, they are also different and there is another thing which have been given in the problem statement that is very important that we have to maintain a pinch temperature up 20 degree Celsius. If we go back to the problem page. So, it is delta T mean that is pinch temperature 20 degree Celsius; that means, anywhere in the network the difference of temperature between 2 streams should not be below 20 degree Celsius.

So, this depends on the decision this is a design diffusion decision because if we go for low pinch temperature this temperature difference is called pinch temperature. So, if we go for a low pinch temperature let say we go for 10 degree Celsius, then we have to have very good heat exchangers and; obviously, there is a gain that by that we will be able to recover and good amount of thermal energy, but we have to pay a penalty that we have to have very good heat exchanger costly heat exchanger.

So, goal of hen analysis or a hen synthesis heat exchanger network synthesis, this will be minimum utility we will use both the hot utility and the cold utility in the minimum quantity.

So, that will reduce our running cost of the plant then we have to see which stream should be match should we match with which other stream because that will give us the total heat exchanger network. So, that also you have to find out that for getting the minimum utility what kind of stream matching we should go for and then the number of heat exchanger needed. So, that also we should make from these heat exchanger network synthesis and n temperature of the heat exchanger. So, we have assumed all the heat exchangers are 2 stream heat exchangers. So, if there are if these are 2 stream heat exchangers then we will also be able to predict the four temperature at the at the ends of the heat exchanger.

Inlet end and exit end of the heat exchanger. So, these are the thing, we will get from the heat exchanger networks synthesis probably we will get some auxiliary benefits also which I will discuss as we proceed.

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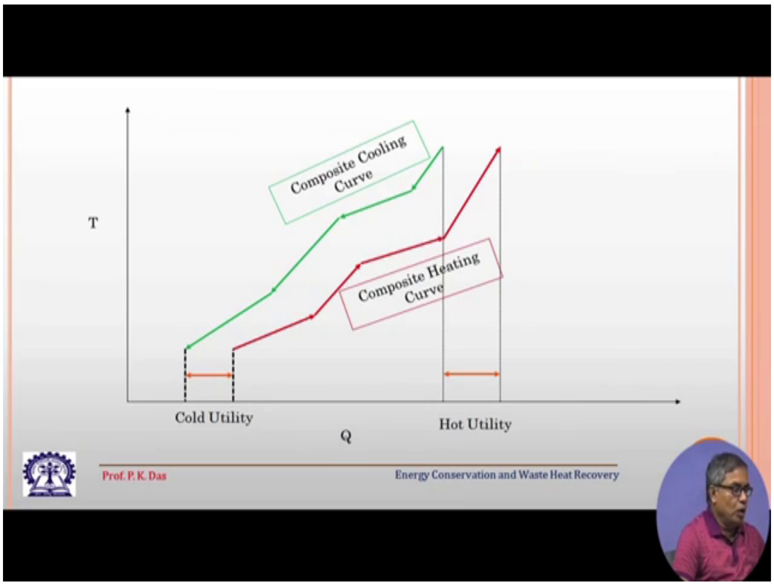

So, here what I explained is the methodology; what we try to do? We first see that all the hot streams are combined together. So, as if there is a single hot stream and if there is a single hot stream unlike a single heat exchanger its heat capacity rate will change throughout the length of the heat exchanger; the heat capacity rate will not be this end similarly all the cold streams will be combined together and what we will get one composite cooling curve.

That is the hot stream is getting cool and one composite heating curve that the cold streams are or the combined cold streams are getting heated now you see there is some sort of overlap between these 2 curves. So, if I extend this line and if this line if we consider; so, in within these 2 lines, the curves are overlapping with each other. So, in this portion there would be possible heat transfer between the cold streams and the hot streams. So, this is what we will target for energy saving, but even with this heat exchange between these 2; between these 2 super streams because now the it can be called a super heating super or composite cooling stream or super cooling stream and this is a super heating stream.

So, even if we considered these to composite steam and heat exchange between them we will not be able to bring all the hot streams to their target low temperature by in this internal arrangement. So, maybe we have to use some sort of cold utility. So, this shows how much cold utility will need to use schematically of course, this kind of problem can be solved graphically which becomes cumbersome when the number of streams becomes large , but graphical representation gives a good understanding. So, the in between these 2 portion this shows the internal heat exchange between the streams and this shows the cold utility similarly here you can see that.

This much amount of heat has to be supplied from outside for bringing the cold stream to their target temperature. So, this is the hot utility needed and we can have some sort of idea regarding pinch take temperature also from these 2 curve, you see if we try to bring these 2 curve close together then more amount of internal heat exchange is possible and very less amount of cold utility and hot utility are needed. In fact, probably one can get a situation that only one utility of minimum quantity either hot utility or cold utility will be needed and if we try to do. So, you will see that the temperature between these 2 curves is decreasing. So, let us say this is at TH and locally this is at TC, if we try to bring them close together, then TH minus TC will be reducing.

Now, how far we can reduce it we can reduce it up to the pinch temperature we have specified at the beginning of the problem. So, we cannot reduce them below 20 degree Celsius. So, that is the significance of pinch temperature in connection with the composite cooling curve and composite heating curve. So, once we have this idea let us now go to the solution of the problem the solution of the problem the way Linnhoff and Hindmarsh, they have they splint it or they have proposed it; it is a tabular method of solution of the problem.

Well again with the help of computer one can have different type of algorithm for solving it, but here we will do hand calculation only four streams are there and we will follow a logic which will be best understood with the help of a table.

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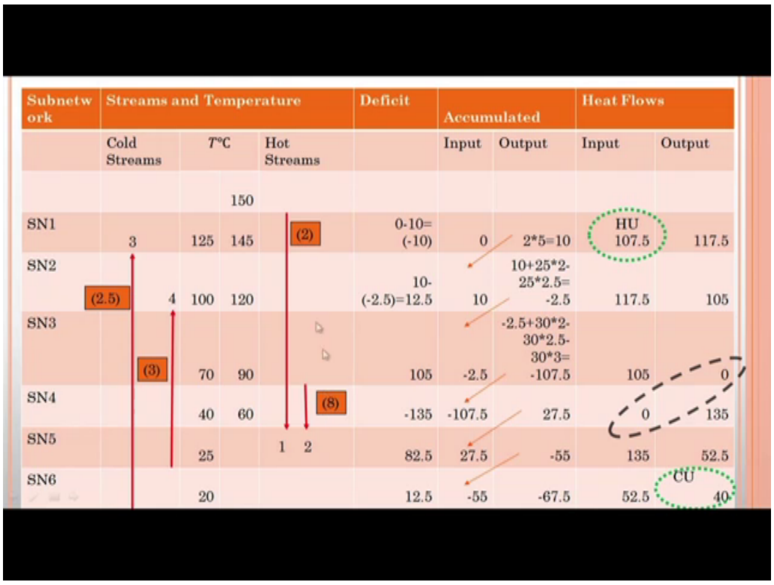

Subnetwork	Streams and Temperature				Deficit	Accumulated		Heat Flows	
	Cold Streams	T°C		Hot Streams		Input	Output	Input	Output
			150						
SN1	3	125	145	(2)	0-10= (-10)	0	2*5=10	HU 107.5	117.5
SN2	(2.5) 4	100	120		10-(-2.5)=12.5	10	10+25*2-25*2.5= -2.5	117.5	105
SN3	(3)	70	90		105	-2.5	-2.5+30*2-30*2.5-30*3= -107.5	105	0
SN4		40	60	(8)	-135	-107.5	27.5	0	135
SN5		25		1 2	82.5	27.5	-55	135	52.5
SN6		20			12.5	-55	-67.5	52.5	CU 40

So, now I show the table, before going to the table; let us go to this four streams. So, you see in the problem, if we have combined these four streams, then we are having certain temperature like this is the temperature, lowest temperature of the heat exchanger network; this is some in between temperatures which has been specified by the problem, this is one of the temperature of the specified in the problem, this is a temperature to reach a particular hot stream has to be cooled this is; similarly, the same temperature to which the other hot stream is to be cooled.

So, all these temperatures are some temperatures given in the problem. So, these are known that we have to avoid by these temperatures because they are specified by the problem if it is show then we come here. So, I have the lowest temperature is 20 degree, we will start from here and the house temperature is 150 degree you see. So, I will start from here. So, here there are 2 cold streams a 3 or four 3 and four and the heat capacity rates are given besides this streams.

So, there are 2 hot streams this is one and 2 and heat capacity rates are given and then the temperature and there is a column for temperature and here you see the temperature which are specified in the problem for the cold stream. So, they are given here like you see that one cold stream starts at 20 degree Celsius is it goes up to 125 degree Celsius another cold stream starts at 25 degree Celsius it goes up to hundred degree Celsius. Similarly here 150 degree Celsius and 60 degree Celsius, then another hot stream is from 190 degree to 60 degree Celsius. So, then what we do we are synthesizing the network we try to identify small networks which are called sub network or SN.

SN 1, sub network 1, sub network 2, sub network 3, like this; what are we getting from here? So, sub network 1 if we start from the highest temperature. So, in that range we find that the hot stream one hot stream is to be cooled from 150 to 145 degree Celsius why 145 degree Celsius because below 145 degree Celsius below 145 degree Celsius, we will have some other interaction. So, if it is 140 degree, 145 degree Celsius, then the cold side the temperature what could be the cold side temperature.

The cold side temperature is 125 that is the highest temperature of one of the cold stream and how we have identified that this should be 145 because we want to maintain a difference of 20 degree. So, that is why it is 145. So, 150 is told 125 is specified in the problem, but 145 we are getting because we are maintaining a difference of 20 degree Celsius. Similarly if we go to the next level what we will that one other temperature for the cold stream is a 100 degree Celsius. So, hot side the corresponding temperature could be we are notice here adding 20 degree Celsius, it could be 120 degree Celsius, then we reach where there is a supply temperature of a hot stream that is 70 degree Celsius and then sorry that is 90 degree Celsius. So, if it is 90 degree Celsius then.

Cold side temperature will be probably 20 degree less than that it will be 70 degree. So, similarly all the other temperature values we will get. So, you see we are getting some sort of sub network. So, in this first sub network, there is only one stream that is changing its temperature from 150 to 145, in the second network; we are having 2 streams one is changing its temperature from 145 to 120; another is changing its temperature from 100 to 125. Similarly we can identify the other sub networks. Now we go to the solution some sort of a calculation.

So, what we do we start with the topmost network; that means, the network which is having the highest temperature; obviously, the network where there is only one hot stream and it is changing its temperature from 150 to 145 degree Celsius. So, what is the difference of temperature the temperature difference is 5 degree temperature difference is 5 degree and the heat capacity rate is heat capacity rate that is your 2. So, 2 into 5 10. So, the deficit what this heat sub network will have that is equal to 0 minus in output minus the input minus output there is no input; input minus output is the deficit. So, it will have a minus 10 unit of deficit.

Then what is the output of this particular sub network; that means, sub network one will as the input of sub network 2. So, this has got an input of some network 2 that is 10 and then we consider that there are 2 stream; one is having 2.5 heat capacity rate another is having 2 heat capacity rate we know what does the temperature difference. So, we do some small calculation the way it is given here from there we get the output is equal to minus 2.5. So, what will be the deficit output input minus output 10 minus minus 2.5 that is 12.5. So, that is our deficit similarly we calculate we calculated the deficit here.

Now, we will have this 2.5 minus 2.5 as the input of the next sub network and we can do calculus calculation; the way it has been written here. So, we will get the deficit. So, similar way, we complete the 3 columns that is deficit column input column and output column. Now you see with all this thing we have got a total deficit of minus 67.5; not only that output somewhere we are getting minus 107.5 which the largest negative number. Now we are considering one energy casted. So, heat is getting transferred from high temperature to low temperature and not only that it is getting transferred from a higher sub network to a lower sub network.

Now, if we have to and while constructing the sub network we have we have maintained or we have not violated the first law of thermodynamics, but when we are considering heat transfer from the upper sub network to the lower sub network, we should not also violate second law of thermodynamics. So, negative output is not allowed if negative output is not allowed then our input has to be changed, how do input has to be changed by putting some sort of additional input we have to make this negative output as zero. So, that is what we have done in the next stage.

So, here to start with we had 0 input, we will put 107.5 as the input initially and with that we will redo the calculation if redo the calculation at one point we will find that input from the upper network is 0 that is allowed that is not violating second law of thermodynamics and this is the output. So, this should be the input to another network. So, these makes some sort of a disconnect or now we can think of that up to this there is one network and below this there is another network and there is no thermal connection between them. So, this point actually is called the pinch point and here we will have the pinch temperature.

Another interesting thing; we will get here; we have started with some sort of input of 107.5 unit, this we have given to given to make all the output positive. So, this is actually the hot utility minimum amount of hot utility which we have to use is 107.5 unit. Similarly, here we can see from the lowest sub network this forty is going out. So, 40 is going out to what. So, this gives the minimum amount of cold utility we have to use. So, this problem I mean this table is very important this is the this is the most important information some of the most important information here getting and this is the backbone of the solution.

We get from here the hot utility minimum amount of hot utility needed minimum amount of cold utility needed and the pinch point where the pinch point will be. So, pinch point, we can see that the pinch point temperature is 70 and 190 which is. So, from here which is exactly the difference of 20 degree Celsius.

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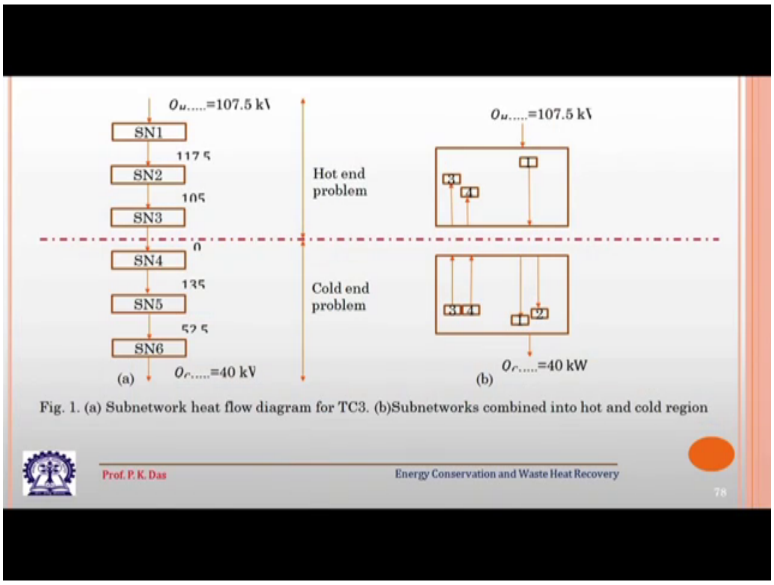

So, this is quite some achievement and now we can show that we have got SN1, SN2, SN3, there is positive amount of heat; heat released from the top network to the bottom network, but SN3 to SN4, there is no heat transfer. So, this is basically the pinch point and here, this is the hot utility and here 40 kilowatt, this is the cold utility. So, the problem has been divided into 2 parts; first part is your hot and problem the top one and the second part of your cold and problem and in between there is there are there is the pitch temperature. So, sub network flow diagram we can see and then the sub network combined into hot and cold region.

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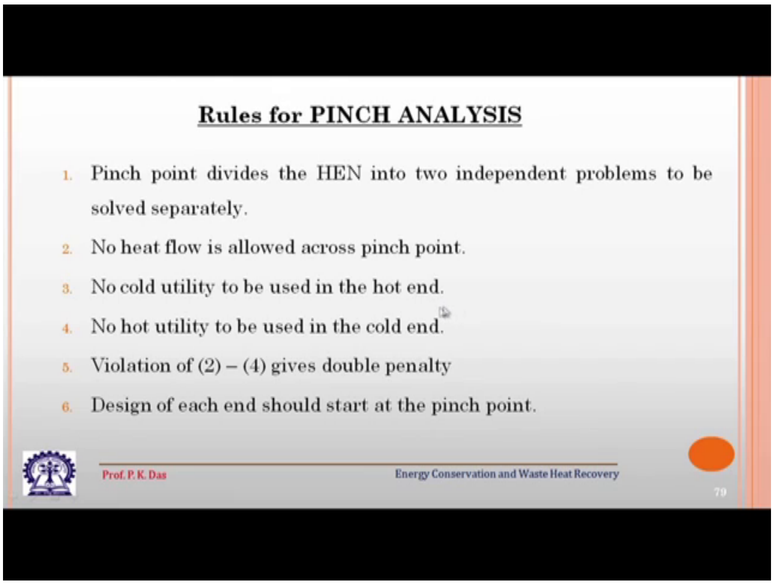

So, hot end and cold end we are getting from this networks with this we now try to state certain rules the whatever we have discussed pinch point divides the heat exchanger network into 2 independent problems to be solved separately. So, now, these 2 problems can be solved separately. So, far what we have achieved we had identified the pinch point we have got how much get what is the minimum quantity of hot utility required and what is the minimum quantity of cold utility required this is what we have got.

We still do not know the stream matching which stream has 2 match with which other stream that we have not worked out. So, now, it can be worked out and now it can be worked out considering that there is a hot end problem our hot end network and there is a cold end network and these 2 are separate. So, this is the first thing we get second thing we get no heat flow is allowed across the pinch point that is what we have got the pinch point means at the top there are sub network , but from the top sub network to the bottom sub network there is no heat transfer across the pinch point.

Then no cold utility to be used in the hot end this is very important and no hot utility is to be used in the cold end this is also very important violation of 2 to 4; that means, 2, 3, 4, if we violate them. then it gives double penalty. So, this is one thing, we have to keep it in mind that if we use, let us say if we use cold utility at the hot end, then you have to use the cold utility and we have to use to compensate the cold utility same amount of additional hot utility, we have to use at the hot end. So, it becomes double penalty because once we are using cold utility and again you are using same amount of additional hot utility.

So, it becomes double penalty design of each end should start at the pinch point. So, pinch point is the most crucial point.

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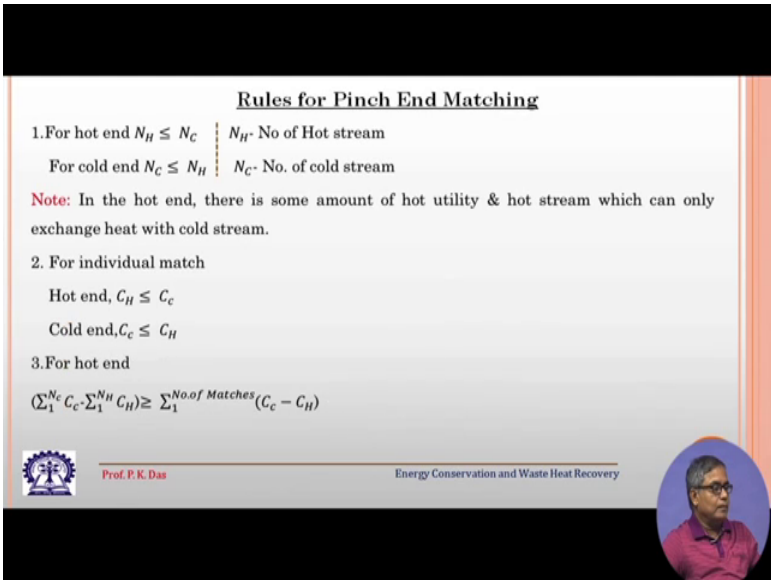

So, design of each end should start at the pinch point then there are rules for pinch end matching for pinch end matching NH number of hot streams should be less than equal to number of cold stream and for cold stream cold end number of cold stream should be less than equal to number of hot stream in the hot end there are some amount of hot utility and hot stream which can only exchange it with cold steam. So, that is why this has to be done and similarly this is for cold stream also for individual match hot end CH the hot stream capacity.

Rate that should be less than cold stream heat capacity rate for a particular match similarly for cold stream for hot end we have to have this kind of a formula for all the matches means we have to satisfy this kind of a criteria for all the matching.

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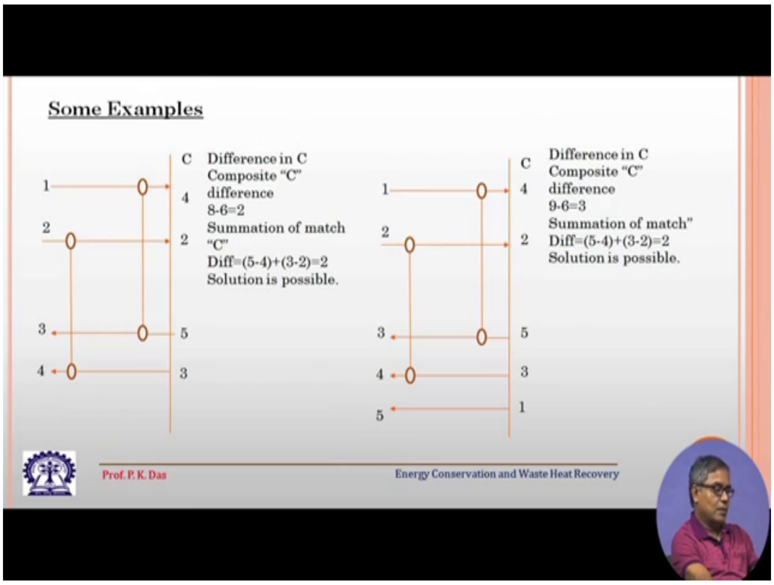

And this will be explained further. So, I think with this I like to end our discussion whatever small thing is left, we can discuss it in the next class.

Thank you.