Process Integration
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Module - 5
Pinch Design Method for HEN Synthesis
Lecture - 8
Remaining Problem Analysis

Welcome to the lecture series on Process Integration, this is module 5, lecture 8, the topic of this lecture is Remaining Problem Analysis. Remaining problem analysis is a method which steers the HEN design in proper direction. That means, it helps the designer to design a HEN which will meet approximately the targeted values which has been computed, before the design. These target values may be of cold and hot utilities, may be of area, maybe of sell, whatever target has been completed or has been conducted before the design, the design should meet those target.

How one will know while designing it will meet the target or not, or the design will be steered in some different way, we have seen that in the pinch analysis or pinch design. There are many alternatives which can be generated during the design, and all conform to the rules of the design that means, many heat exchanger network designs can be completed, and this we have also seen in manier times. And there are alternatives available, which will generate different designs and all the designs will have different area and different cost.

Now, the question is how to steer the design in current direction, so that we get design which will meet our targeted values, maybe targeted hot and cold utilities, and targeted areas. Now, remaining problem analysis is such a tool in the hands of the designer, which helps the designer to design a heat exchanger network, which will meet the target, let us see that.

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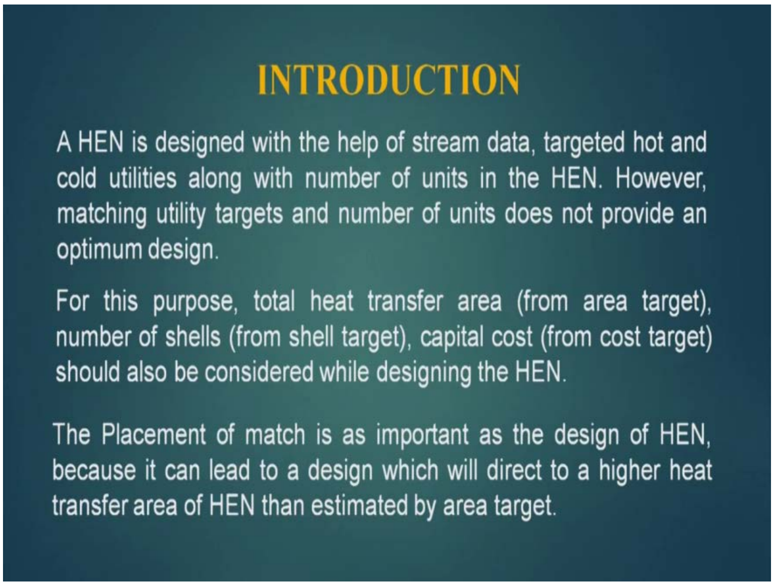

A HEN is designed with the help of stream data, targeted hot and cold utilities along with number of units in the HEN. However, matching utility targets and number of units does not provide an optimum design, we are in such of a optimum design, and how to reach to the optimum design and do not deviate from it is a question. For this purpose total heat transfer area, from area target or number of shells target, number of shells, capital cost target will gives us the cost of the target, should also be considered while designing the HEN.

The placement of match is as important as the design of HEN this we have seen, because there are a number of alternatives which are available have the pinch to place the matches, this can also happen away from the pinch. So, how to select a proper match is very important, because it can lead to a design which will direct to a higher heat transfer area than estimated by area target. This may be possible that we take one design, one placement or two placements and that will lead to a HEN, which will have more area, if those placements area not correct.

That means, each placement has to be judged some way that those placements are correct placement and we will not tax the HEN, in terms of higher cost or higher area or higher number of units or higher cold and hot utilities. Now, who will tell this that this placement is correct and the other placement is not correct, so we should sophisticated method to know whether what I am doing, what placement I am doing for the HEN, is a correct placement or not. And this will be calculated or this will be known, if that placement is increasing the total area of a HEN that means, if that placement is taxing the HEN, in terms of increasing the hot or cold utility or number of units or area, then it is not correct placement; and thus we have to search for another placement which will not tax the HEN.

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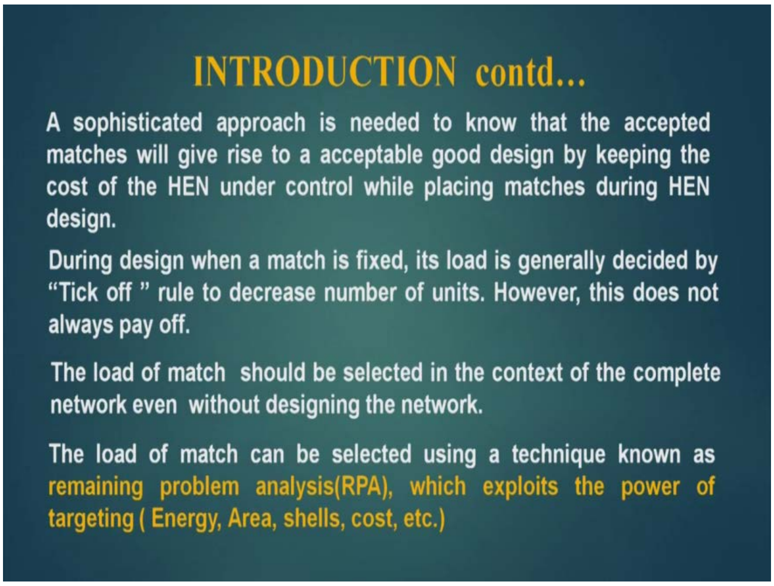

A sophisticated approach is thus needed to know that the accepted matches, will give raise to a accepted good design by keeping the cost of the HEN under control, while placing matches during the HEN design, this is absolutely necessary. During the design when a match is fixed, it is load is generally decided by tick off rule and why this is done to decrease number of units. If we do not accept the tick off rules, the number of units in the HEN will increase, and once is increases its cost will also increase.

And that is why the tick off rule is very important, and if we adhere with the tick off rule, then we can design a minimum number of units HEN however, this does not pay. The load of the match should be selected in the context of the complete network, even without designing the network. That means, the there are two things, one is match the match should also to be selected in context with the total designs, similarly load of the match should also to be selected in the context of the complete network, even without designing the network.

What is that mean that the load of the match or the load should not tax the HEN, in term of increased area or in terms of increased hot utility and cold utility demands. Now, the question is whether I can know this without completing, the design the answer is yes, we can know it without designing the network, then how this can be done, because we have a set of targeting procedures which without the design tells us important parameters. Like what will be the cold and hot utility demand, what will be the number of units, what will be the number of shells, what will be the area, what will be the cost of the network without even designing.

So, in the sophisticated method which we are going to device, which will steer us in the correct direction of the design will use the power of targeting for this purpose, so that without designing the network, we will able to know whether a placement or a load of a match is taxing the network or not. The load of match can be selected using a technique, known as remaining problem analysis or RPA in short form, which exploits the power of targeting, energy target, area target, shell’s target or cost target.

So, the remaining problem analysis which steers the design in correct direction, is based on the targeting procedure, and it exploits the power of the targeting. And hence without going through the complete design, we can steer the design with the help of targeting. Now, let us see how a PTA can steer the design, PTA is a targeting tool, so this can also be used for remaining problem analysis to steer the design, so let us try to understand this.

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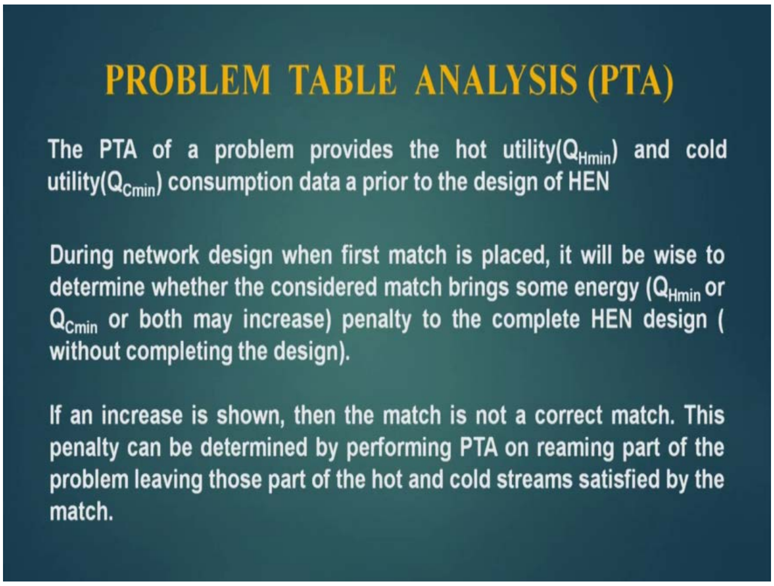

The PTA of a problem provides the hot utility and cold utility consumption data, prior to the design of the HEN this is a well known fact. During network design, when first match is placed it will be wise to determine, whether the considered match brings some energy that is QH minimum or QC minimum or both penalty to the complete HEN design without completing the design. So, if the selected match is taxing the HEN by increasing it is cold or hot utility demand or both demands, then we will say that the match is not a correct match.

Because, it is taxing the HEN and thus I am not moving in the correct direction as well as design is concerned in an increase is shown if a increase is shown, then the match is not a correct match, this penalty can be determined by performing PTA on remaining part of the problem. Let draws it is name, once I put a match and I know how much it is consuming, then on the remaining part of the problem I can again apply the PTA to know, how much taxing is there in terms of hot and cold utility requirements, now this is how it works.

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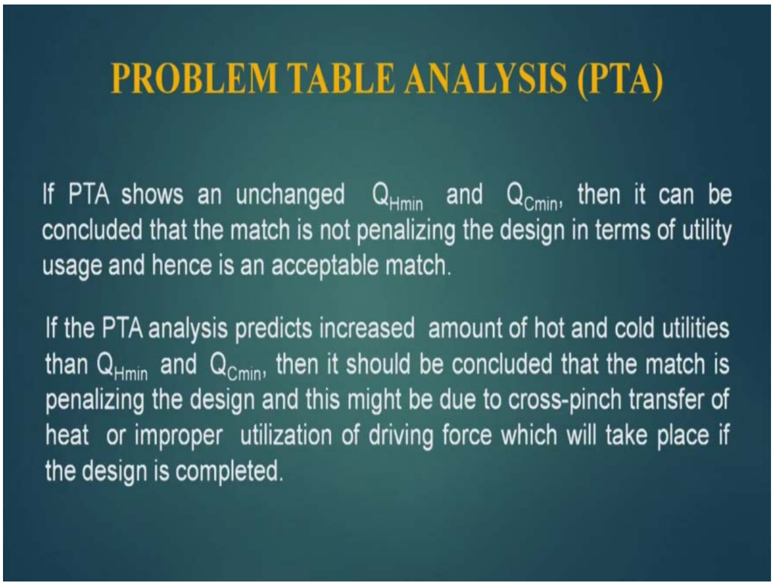

If PTA shows an unchanged QH minimum and QC minimum which is applied on the remaining part of the problem, then it can be concluded that the match is not penalizing the design, in terms of utility is usage, and hence is an acceptable match. But, if I do not see this, then I have to consider that the match is not correct, if the PTA analysis predicts increased amount of hot and cold utilities than QH minimum and QC minimum, then it should be concluded that the match is penalizing the design. And this might be due to cross pinch transfer of heat improper utilization of driving force which will take place, if the design is completed.

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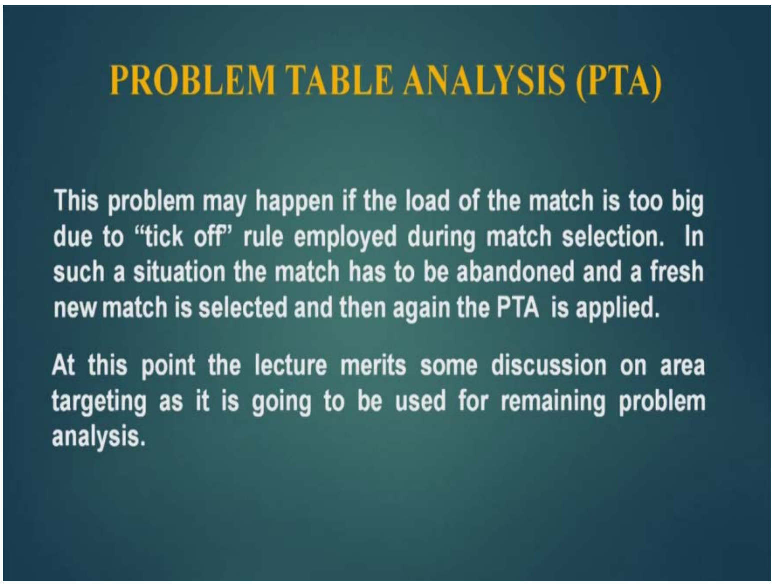

This problem may also happen if the load of the match is too big, due to tick off rules, I have already told that tick off rule does not help always. If the load too much of the match is too much, in such a situation we will generally see that the hot utility or cold utility usage as increased or area as increased. Now, if we fall in such a situation, then the match has to be abandoned, a fresh match is selected and then PTA is again applied to the remaining problem.

At this point of time our lecture merits some discussion on area targeting, as it is going to be used for the remaining problem analysis, I had already told you that any targeting procedure can be used for remaining problem analysis. But, in the present case we will be using area targeting as a source of targeting for the remaining problem analysis. Now, the algorithms, the bath algorithm which we have developed for area targeting is based on vertical heat transfer from hot composite curve to cold composite curve.

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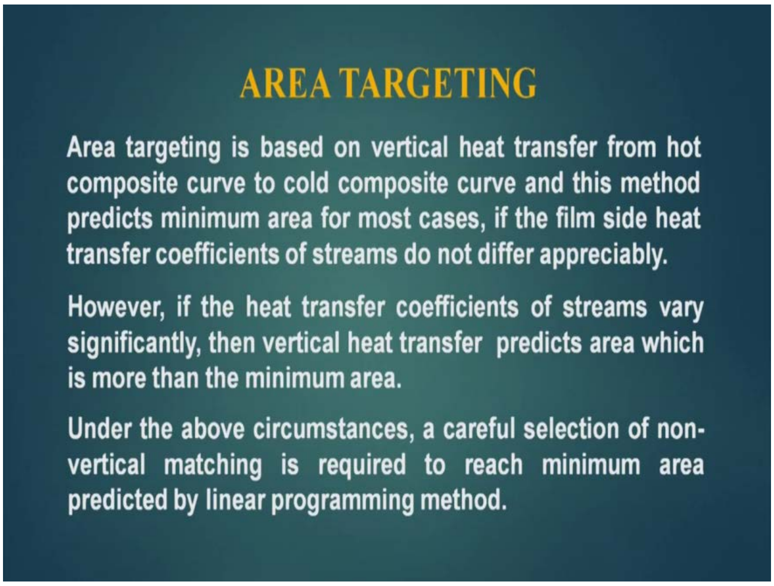

And rather I should say balanced composite curve, if I want to find out the total area including the heatest and coolest. And this method predicts minimum area for most cases, but that is a cache, this will predict minimum are for most of the cases, if the film side heat transfer coefficient of streams do not differ appreciably. This is the condition, pre condition of getting a minimum area and why we are search of in minimum area, because minimum area will provide a minimum cost heat exchanger network; or at least we will try to have a minimum cost heat exchanger network.

However, if the heat transfer coefficients of streams vary significantly, may be more than 10 percent, then vertical heat transfer predicts area which is more than the minimum area. So, what we see or what we saw from the analysis of area targeting, that if the heat transfer coefficient up streams vary significantly, then the bath algorithm which we have used will not provide the minimum area, whatever area it will calculate will be more than the minimum area.

Under the above circumstances a careful selection of non vertical matching is required, why it is required to reach to the minimum area. And this non vertical matching can be done using a linear programming method or non-linear programming methods. Now, let us come straight to the remaining problem analysis.

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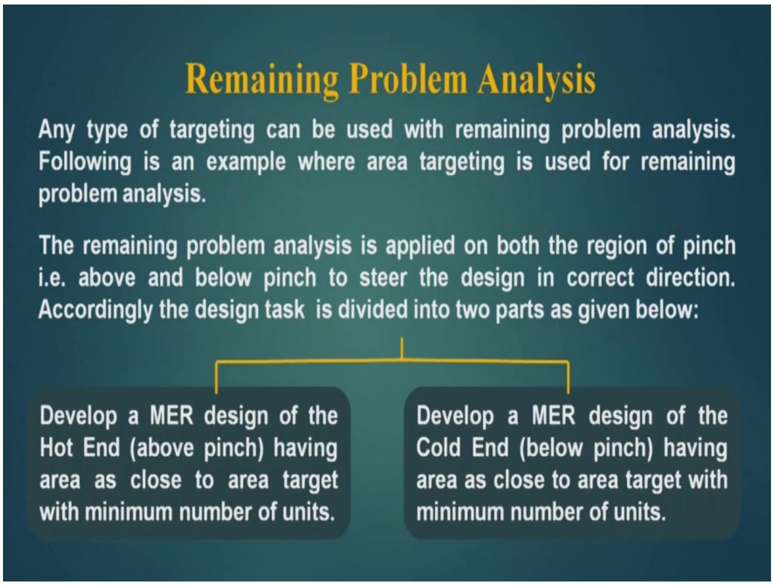

Any type of targeting can be used with remaining problem analysis, the targeting are energy targeting, number of units targeting, number of shells targeting, area targeting and the cost targeting. There are many targeting procedures are available in pinch, any can be used, but for the present problem we are using the area targeting for the remaining problem analysis. Now, the remaining problem analysis in this problem is applied on both the reasons of the pinch, that is above the pinch region and the below pinch region, to steer the design in correct direction.

Accordingly, the design task is divided into two parts as given below, develop a MER design of the hot end that is above pinch, having a area as close as to area target with minimum number of units. And develop a MER design of the cold end having area as close to area target with minimum number of units. So, if I can meet my area targets for above the pinch and I can meet the area target for below the pinch, then I will be able to meet the area target for the complete problem. But, this is not always easy, the design will not always meet the target area, this we will see though we use the remain problem to steer the design in best possible way.

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PROBLEM $\Delta T_{min} = 10°C$

Stream Name	Supply Temp.	Target Temp.	CP (MW/ K)	h (kW/m^2 /K)
Hot Stream	140	50	0.25	0.15
Hot Stream	160	40	0.1	0.15
Cold Stream	40	110	0.25	0.15
Cold Stream	70	100	0.5	0.15
Hot Utility	180	179	-	0.15
Cold Utility	20	30	-	0.15

Now, let us take this problem, where delta T minimum is 10 degree centigrade, there are two hot streams, there are two cold streams and there is hot utility and cold utility. We have provided the heat transfer coefficient, that is stream heat transfer coefficient, for all the streams. As we are using area targeting for the remaining problem analysis, the data on steam heat transfer coefficient is a absolute necessity. Now, in this case we are considering the heat transfer coefficient of all the stream data, as constant equal to 0.15 that means, there is no variation in the stream heat transfer coefficient data. So, when we will use bath algorithm to find out the area target, then whatever area target we will get, will be minimum area of the heat exchanger network.

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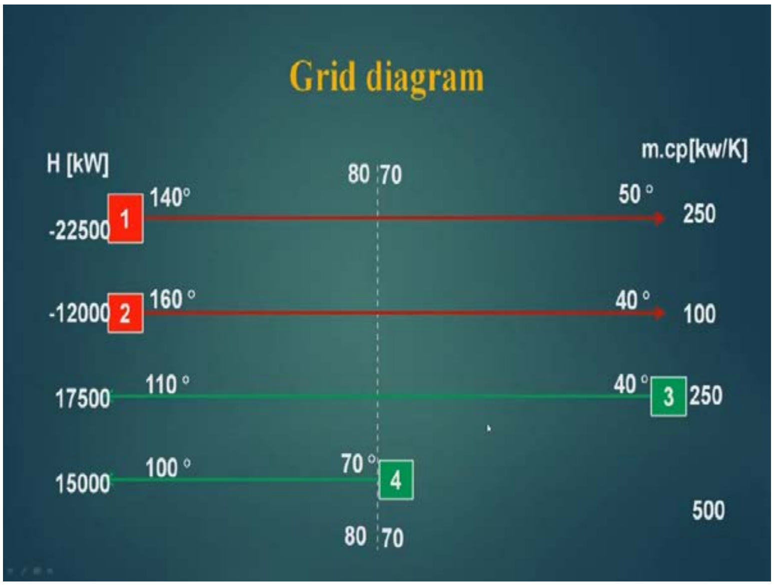

So, this is a stream diagram of the problem, the pinch is at 80 degree centigrade and 70 degree centigrade that means, hot pinch at 80 degree centigrade and cold pinch is 70 degree centigrade. So, with this free diagram, now we will divide this into two parts, the upper pinch area which is shown by this, this part is upper pinch and this part is lower pinch or we call this part is hot end and this part is cold end.

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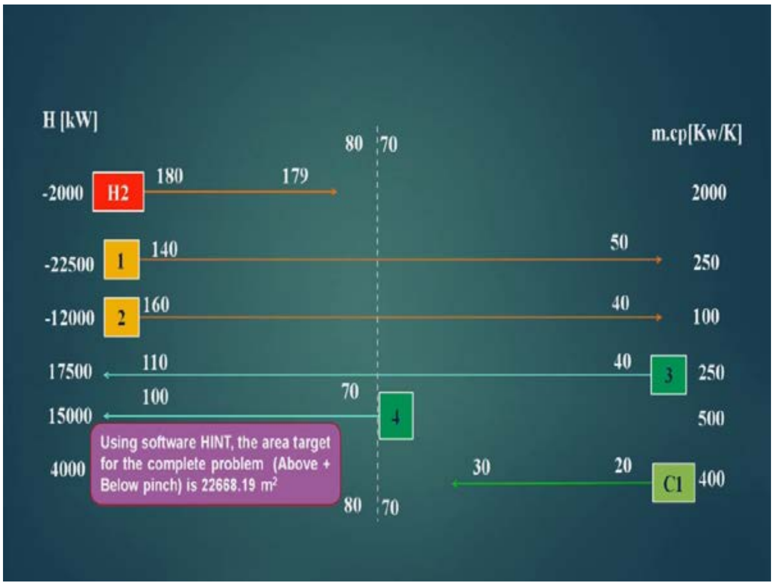

Now, here we have added the hot utility and cold utility, now if we do the area targeting of the complete problem that means, we will find out the area target above the pinch, and we find out the area target below the pinch and then, add them up. We find that the area target gives 22668.19 meter square area, and this has been completed using the hint software is a free software, and in this lecture series we have devoted a few lectures on how to use hint software, and to solve our problems using it. So, in that you will find out how the area targeting can be done using hint software. Now, we start designing the hot end part of the problem.

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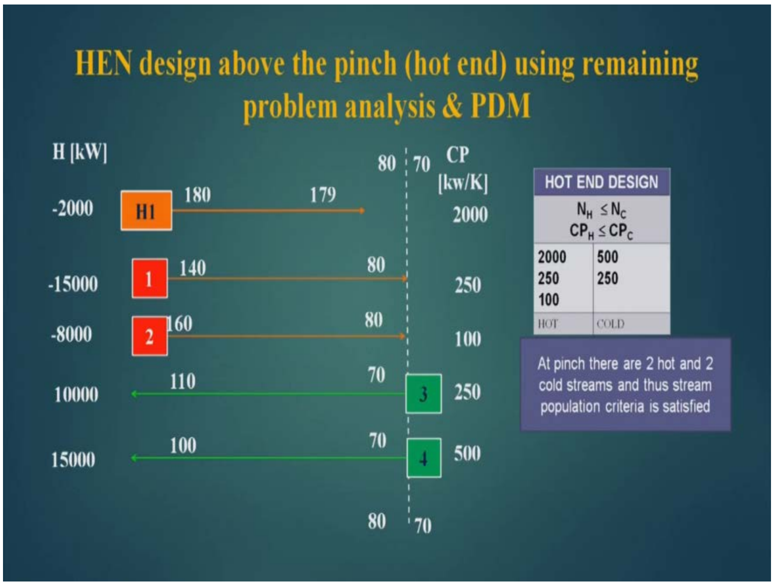

And for the hot end design the rules are N H should be less than or equal to N c, C P H should be less than or equal to C P C and these are the hot streams, and these are the cold streams this 2000 is this stream, which is a utility stream and it is not going to the pinch. So, for this we will only calculate the hot streams and cold streams, which are reaching to the pinch point, so here two hot streams or two cold streams are there at the pinch point. So, N H is equal to N C and hence, this criteria is satisfied this criteria is satisfied similarly, this is for cold stream this, now obeying this C P criteria, now we can of two matches.

We will try with the first match and then, we will target the remaining problem analysis and see whether, the targeted area for the hot end is increasing or not, and if there is taxing, then how much taxing as been there. Now, if I do the area target above the pinch using my hint software, then it gives 13453 meter square, so if I consider vertical heat transfer for the hot end, then my HEN design should be completed within 13453 meter square. And if I am consuming more area than this for the hot end design, then my design may not be very very efficient and I have to search west to make it efficient.

And for this purpose placement of matches is very important, that we will see now, so we will try to meet this targeted amount of area that is 13453 meter square through the design. Now, the first design can be from stream 1 to stream 3, if I go here this is stream 1 to stream 3, so this is 250 and 250, so 250 to 250 we can design, so this is according to the CP of stream.

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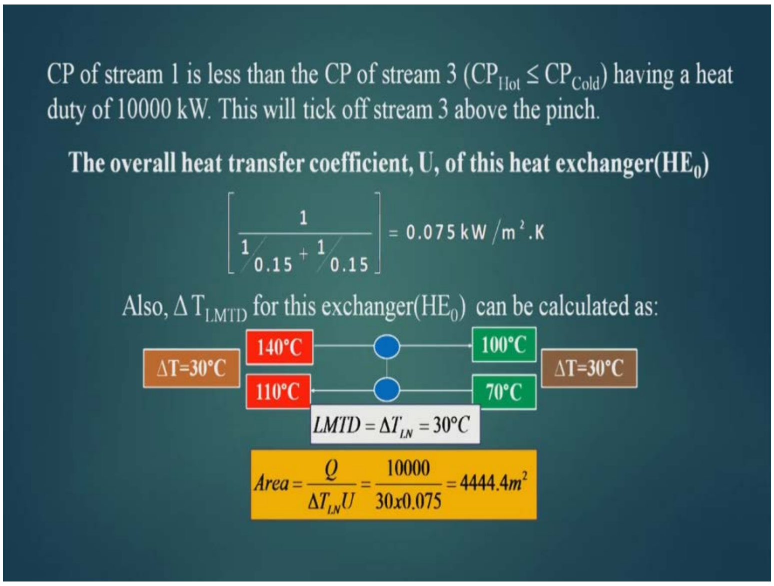

So, the CP of stream 1 is less than or equal to this CP of stream 3 having a heat duty of 10000 Kilowatt, this will tick off stream 3 above the pinch. Now, if I do so the U of this heat exchanger can be computed with this formula which comes out to be 0.075 Kilowatt. And if I consider the LMTD of this heat exchanger this end is 30 degree, this end is 30 degree, so my LMTD will be 30 degree, I cannot calculate using this to LMTD, because delta T 1 is equal to delta T 2, so it will make that a 0 divide by L N infinite.

So, the LMTD will be equal to, because delta T 1 and delta T 2 are same, so it will be 30 degree, so area is equal to now, Q by delta T L N U and this would be remembered that is delta T 1 is equal to delta T 2, I cannot use the LMTD formula, and I can directly use the value of the one of the delta T's. So, area is equal to Q delta T L N by U is equal to 10000 30 into 0.75, it comes out to be 4444.4 meter square, so this is the heat exchanger, we call it instruction with 0.

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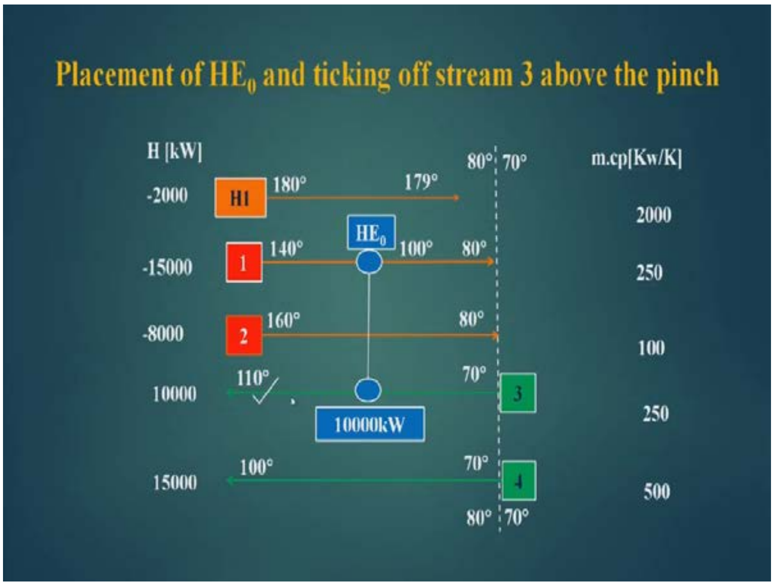

And place between 1 and the 3 streams and the heat carrying capacity of this stream is 10000, so it can be tick off this stream, because why the placing matches will be using the tick off rule to decrease the number of heat exchangers. So, we have use the tick off rule and they found that, this match is as for the rules and regulations of the pinch. Now, if I do this these stream temperature is dropped up to 100 degree centigrade, when I pass on 10000 Kilowatt from this stream.

So, remaining part of this stream is 100 to 80 this is very important, because I have to carry out a analysis on remaining part of the problem. So, once this exchange take places, then I have this hot utility from 180 to 179 having C P 2000, then this stream 1 will be from 100 to 80. And streams 2 has not been loaded, so it will remain from 160 to 80, there will be no 3 stream, because it has been ticked off in the remaining problem, but 4th stream will remain as it is. So, we have computed what is the heat exchanger area for this heat exchanger, which has got a capacity of 10000 Kilowatt which comes out to be 4444.4 meter square.

Then what we will do, we will apply the area targeting for remaining problem, in the remaining problem H 1 will be completely there, but stream number 1 will be from 100 to 80 degree centigrade, 2 will be from 160 to 80 degree centigrade, there will be no 3rd streams in the remaining problem. 4th stream will be there as it is on this free diagram, if

I apply the area targeting, then I will say that I am applying the area targeting on remaining problem of this design.

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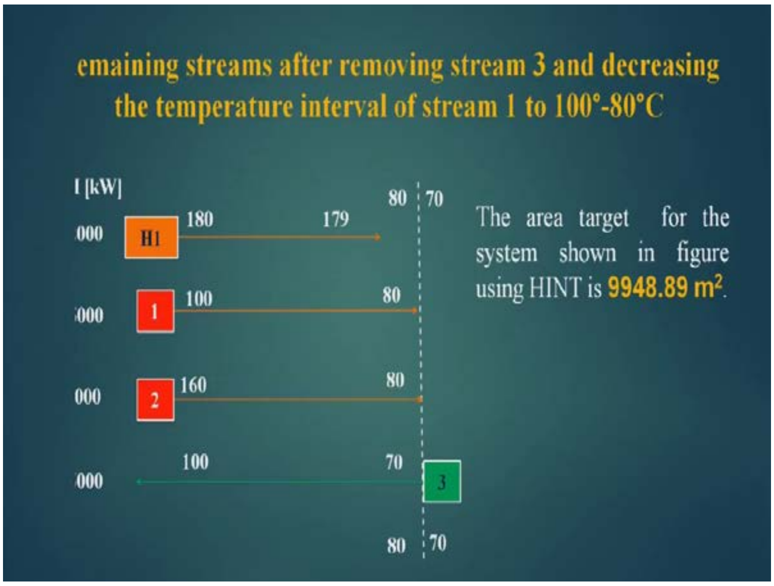

Now, remaining streams after removing the stream 3 and decreasing the temperature interval of the stream 1 to 100 to 80 degree centigrade, this is my remaining problem, as I have discussed. Now, if I apply the area target for the system shown in figure using hint, the area for remaining problem is 9948.89 meter square. So, now the total area is the area of the heat exchanger 0, that is 4444.4 meter square plus this area and this area plus the area of the heat exchanger is 0, should not be more than the area which has been targeted at the start of the problem for the hot end.

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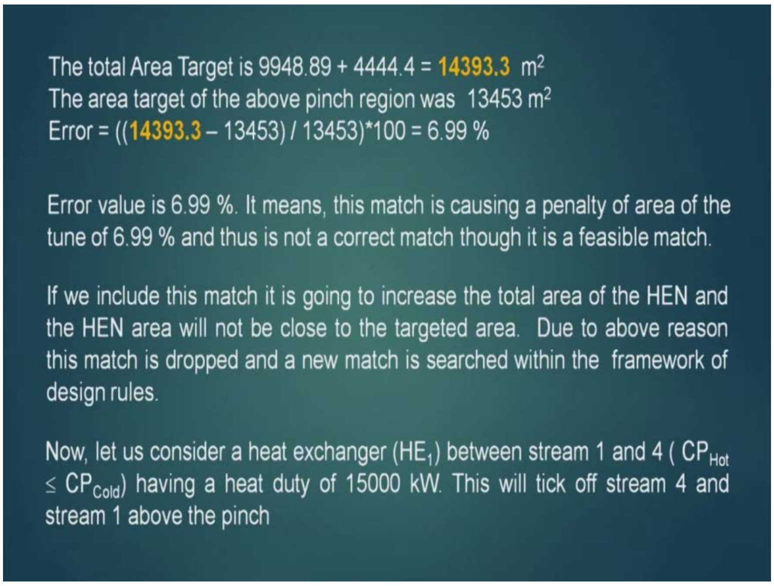

Now, this we will see, now the total area target is now 14393, because this is the heat transfer area of the heat exchanger 0, and this is the targeting of the remaining problem analysis, so it is 14393.3 meter square. The area target for the above pinch region was this, that is 13453 meter square, so my design was suppose to meet this target, but what has happened it has increased now. That means, the heat exchanger which I put, heat exchanger is 0 or the match which I selected is taxing the heat exchanger network design.

And how much taxing in a 6.99 percent, if I select that match, then the heat exchanger area is being taxed by 6.99 that means, almost 7 percent taxing is taking place. So, error value is 6.99 percentage, it means this match is causing a penalty of area of the tune of 6.99 percent, and thus is not a correct match, though it is a feasible match. As far as feasibility is concerned of the design, I cannot put a question on that, but as far as match selection is concerned, because I have alternative matches. So, I should leave this match because, it is penalizing the area of the heat exchanger network, so I should try for another match in place of it.

So, when I search for another match, then I am find some, so this match is dropped now the other match which will be placed in place of it is between stream number one, and stream number 4, having a duty of 52000 Kilowatt, this will tick off stream 4 and stream 1 above the pinch.

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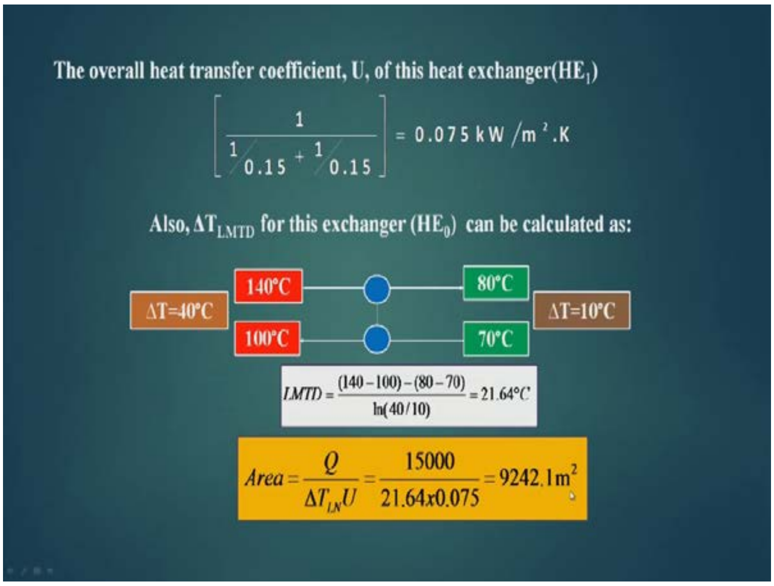

So, I go for a another match, and if I compute the U for this match it is 0.075, if I compute the terminal temperature, because it will tick off both the streams stream number one and stream number 4. So, this will be the temperatures, they are not going to change, so delta T here is 40, delta T here is 10, I can compute LMTD using this formula it is 21.64 degree centigrade. So, area can be computed by using this formula U divided by delta T L N U and when I put up this values and this value here, it comes out to be 9242.2 meter square; so this area of this heat exchanger or match will be 9248.2 meter square.

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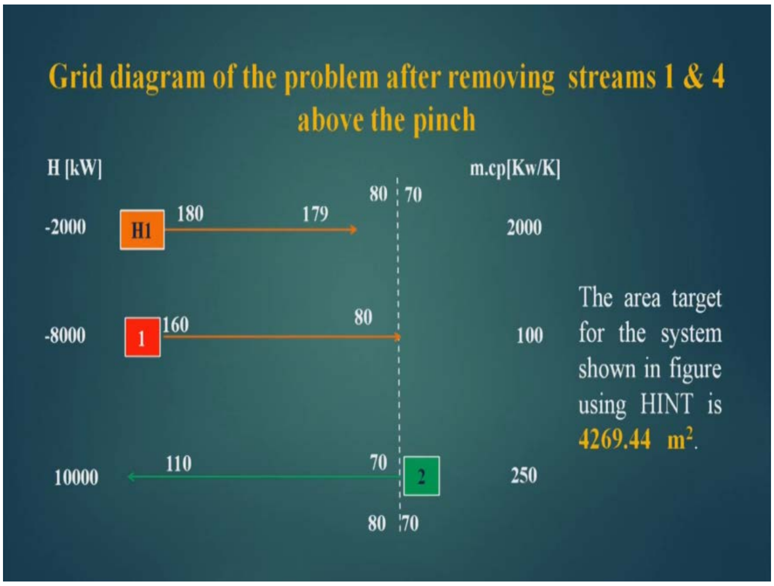

So, now I am putting a match here 1 to 4 and which will tick off my 1, as well as 3, now I do not know whether this match will tax the total area or not, this I have to compute. So, I know what is the area of this match, then I will find out the area target of the remaining part of the problem, so remaining part of the problem will have H 1 will have stream number two, will have stream number three only. Because, 4 number stream and 1 number stream has been ticked off, so this will removed from the remaining part of the problem.

So, I will apply the area targeting on remaining part of the problem, and we will see whether this design is taxing the overall targeted area for the hot end or not, this is remaining problem analysis. So, remaining problem if I target using, it is area is coming as 4269.44 meter square, so I can now run my computation.

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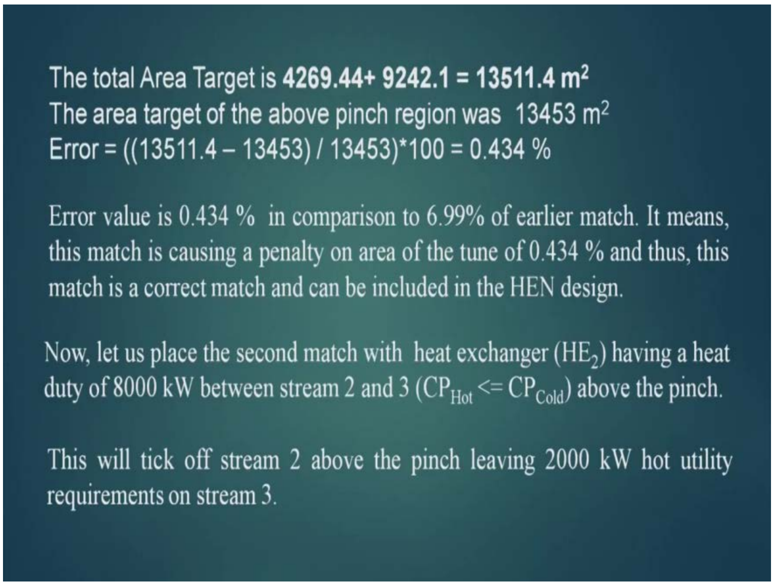

That total area target is 4269.44 it is coming from remaining problem analysis, and this is coming from the match which is heat exchanger number 1, 9242.1, so total area is 13511.4 and the targeted area above the pinch was 13453 meter square. So, this is little bit more than this the targeted value, now error being 0.434 percent that means, this match is taxing the total area by 0.434 percent. As this is far far less than the 6.99 percent which has been taxed when I put heat exchanger 0, it means that this match is causing a penalty on area of the tune of only 0.4 percent; and thus this match is a correct match and can be included in the HEN design.

So, what we did we saw two matches, one mach was taxing the area, the other match was taxing the area, but very, very little and hence the match which is taxing the area very very little or very less, I will select that match for the HEN design. Now, we will go for the second match of the hot end, now let us place the second match with heat exchanger H E 2 having a heat duty of 8000 Kilowatt between steam two and three. And here the C P rules are adhered, now this will tick off stream 2 above the pinch, leaving 2000 Kilowatt hot utility requirement for stream 3.

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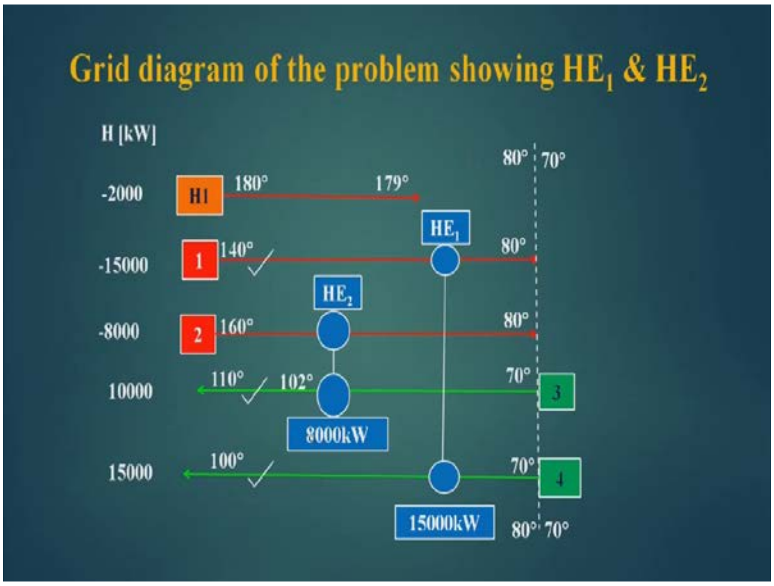

So, the first match we already accepted, because it is not taxing the total heat area of the heat exchanger network match on the 0.4 percentage or so, now we put the second match. Now, the second match will not tick off this, second match will tick off this and there will be it will heat the stream number 3 from 70 degree centigrade to 102 degree centigrade. And from 102 degree centigrade to 110 degree centigrade it will be heated by H 1 and then only it will ticked off.

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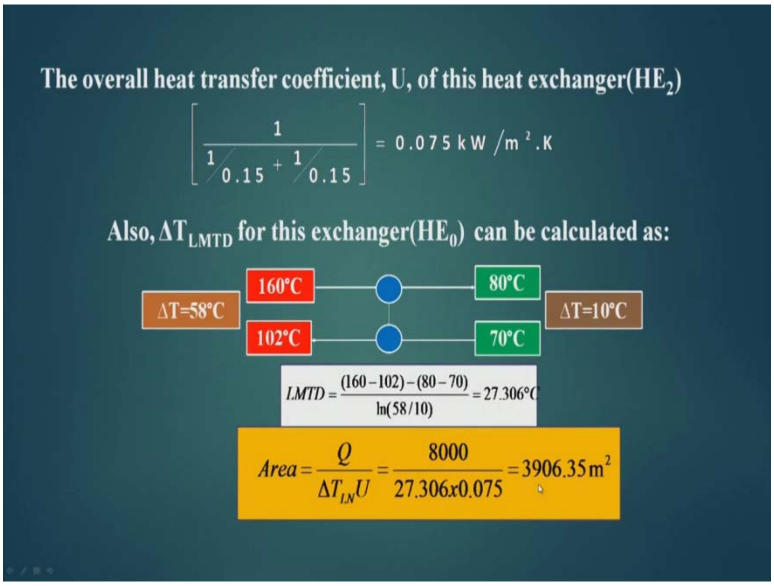

So, we calculate the heat transfer area requirement for this, so it is heating up to 102 degree centigrade, so here this is 58 delta T and here this is 10, so LMTD is 27.306 degree centigrade area is given by this. So, 8000 divided by 27.306 into 0.075, so area comes out to be 3906.35 meter square, so now, we go for the calculation for the second match also.

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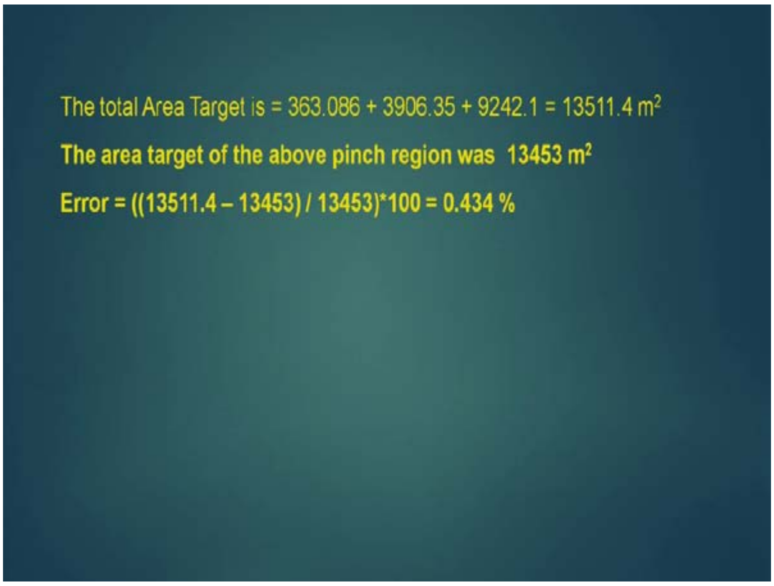

Now, here the first match gives this much of area, second match gives this much of area and the remaining problem gives 363.086 area. So, total area comes out to be now

13511.4 meter square and the target area above the pinch region was 13453 meter square, and if I find out the increase in error it is 0.434 percent. And hence, the second match is only taxing or I should say this two matches are only taxing this much of area and hence both matches can be accepted; so first match I have already accepted, second match is accepted.

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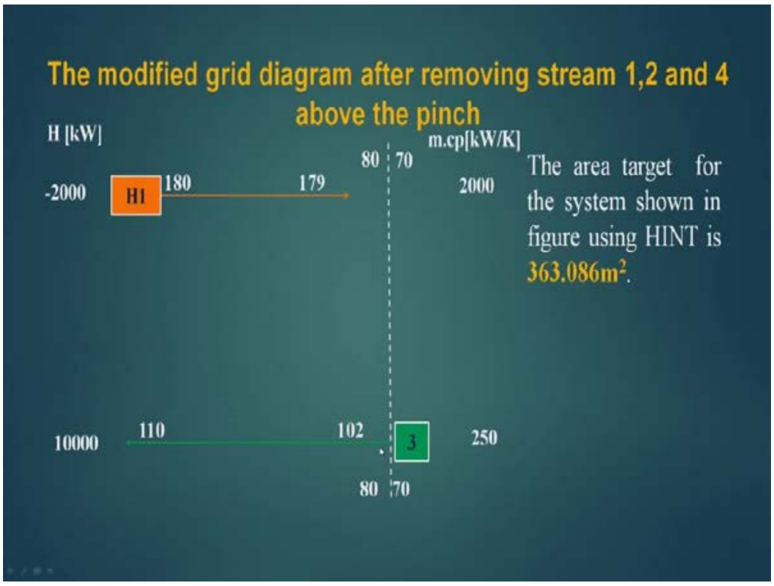

So, after the second match this is the remaining problem, and when we use hint for remaining problem analysis, this is 363.086.

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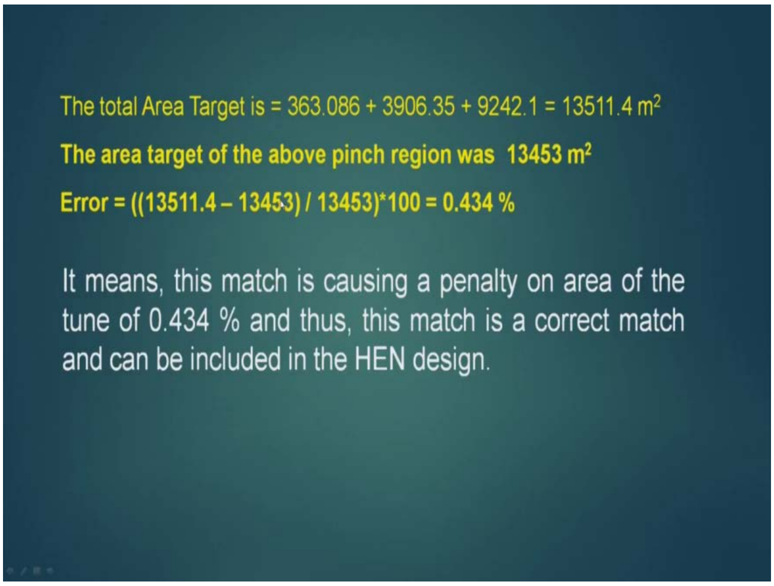

And we have seen in here, this value.

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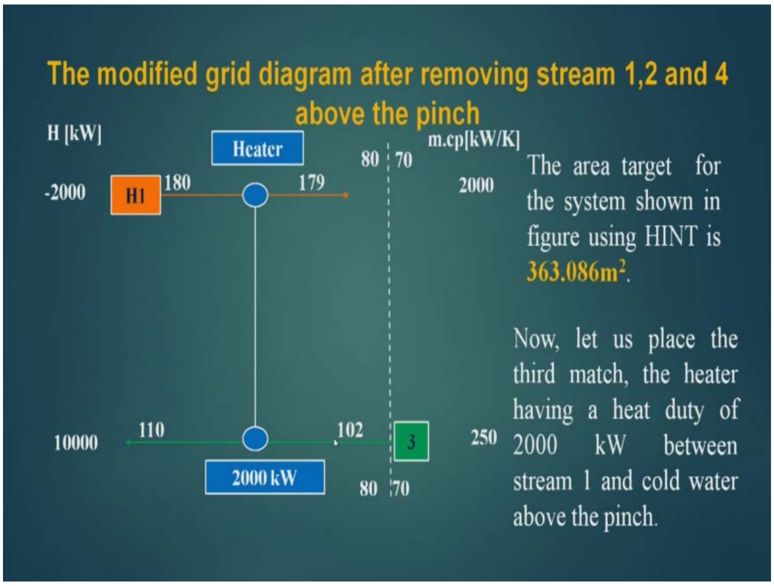

Now, let us place the third match, the heater having a heat duty of 2000 Kilowatt between stream 1 and the cold stream above the pinch, so you put a match here, this is a heater and this capacity is 2000 Kilowatt. Now, what we will see from here that in this design we have able to match the hot utility requirement, which was 2000 Kilowatt we are able to match this is, but the area requirement as been increased by 0.4 percent.

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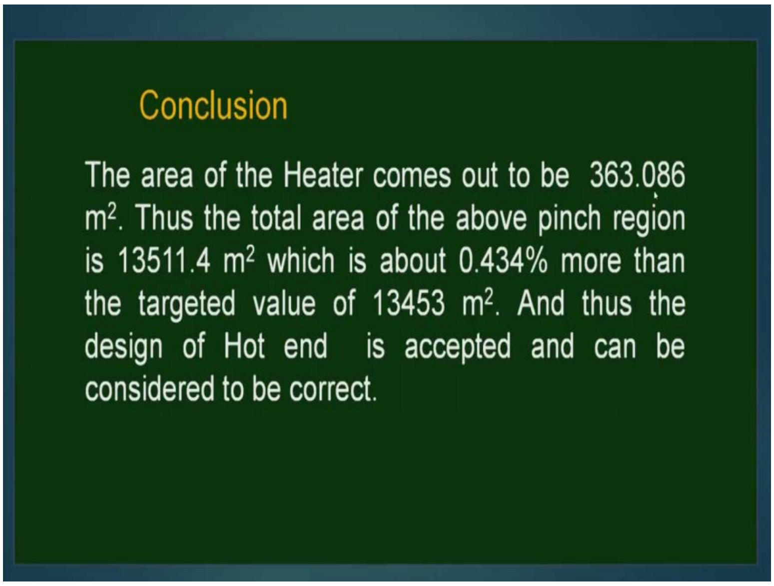

Now, if you see the area of this, then this is 363.086 meter square, so the area of the heater comes out to be 363.086 meter square, thus the total area of the above pinch region is on 13511.4 meter square which is about 0.434 percent more than the targeted value of 13453 meter square. And thus the design of hot end is accepted and can be considered to be correct, because the penalty is very less, if I would have taken the other route that means, I would have accepted that the heat exchanger 0 which was done at the start of the design, then the scenario should happen different. And this error should be about 7 percent also in straight of 0.4 percent and hence the proper match placement has been this.

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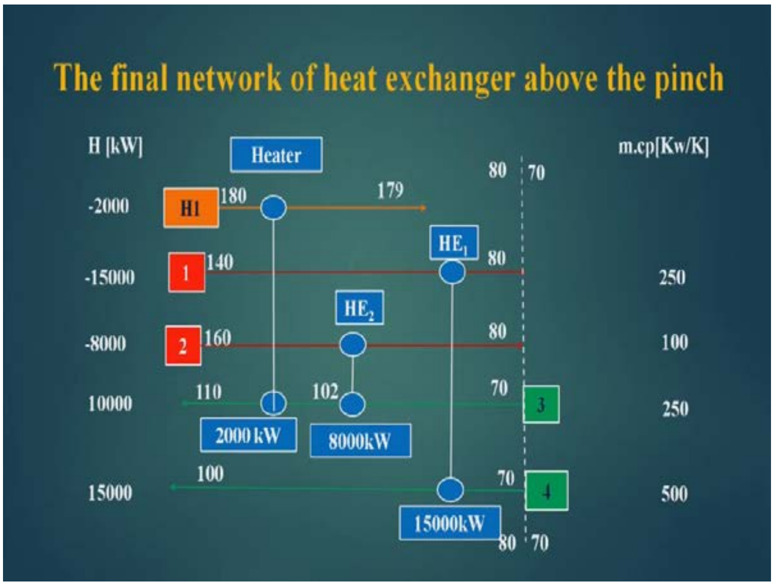

Now, the same exercise now has to be repeated for the cold end design.

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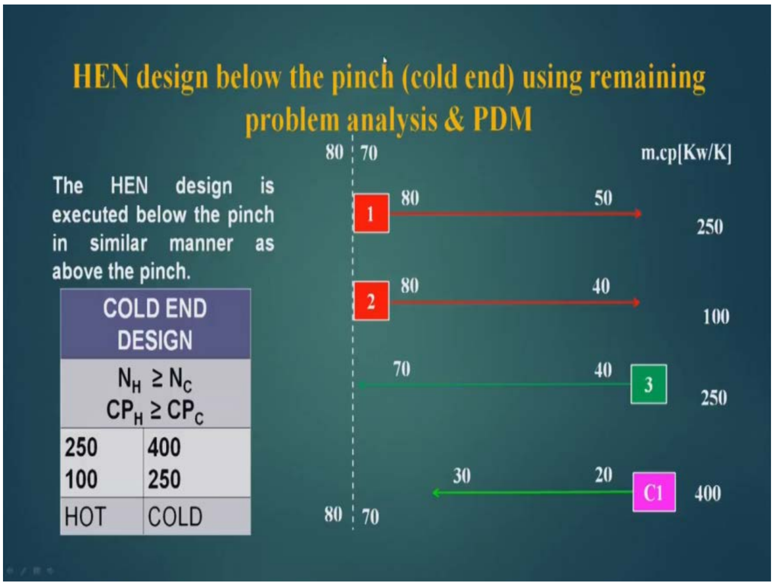

So, this is my cold end design, for the C P table for the cold end design and the design rules have been given, N H should be greater or equal to N C. Now, here one cold stream is reaching pinch and two hot streams are this crossing pinch, so N H is 2 and N C is 1 and that is why this is satisfied. Now, this my C P rules which has to be adhered when putting of a match, so what I will doing first that I will apply the area targeting to the this part of the heat exchanger network, which is the cold end.

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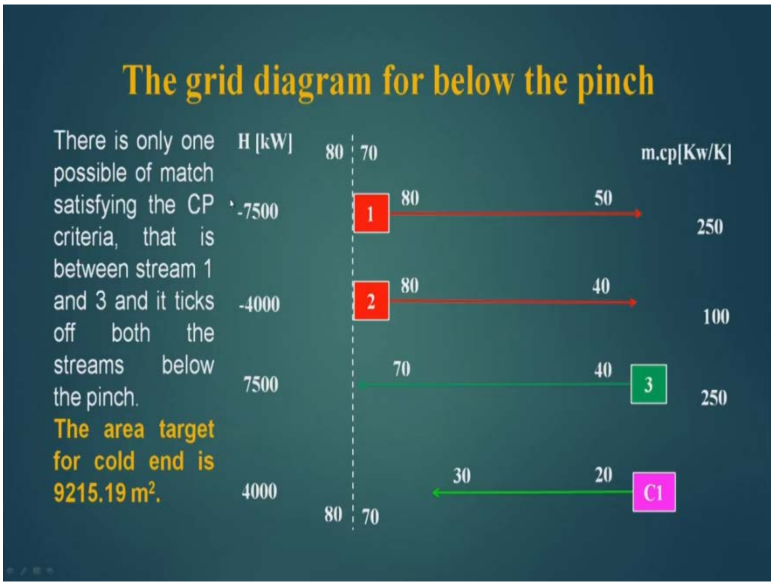

Now, the area target for the cold end design is 9215.19 meter square, now if we see this there is only one possible match satisfying the C P criteria, and that is between stream 1 and 3. So, stream 1 and 3 can be matched, because this is 250 and 250.

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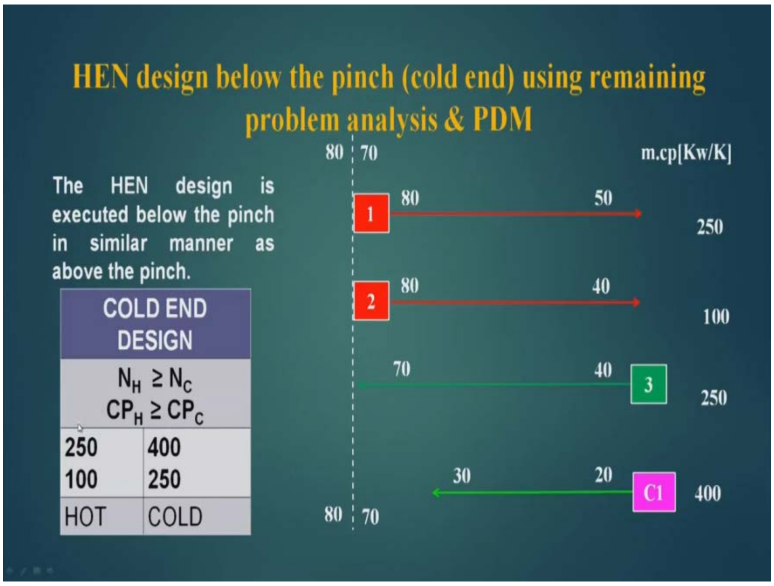

And my rule tells that my C P H should be greater or equal to C P C, so this is equal to 250 is equal to 250, then only this match can take place, this match cannot take place because 100 is less than 250. So, I have only one possibility of matching, so there is no alternative available and hence, I have to go for that matching and then, this stream will be left out which will be cooled down by the coolant that is cold utility C 1.

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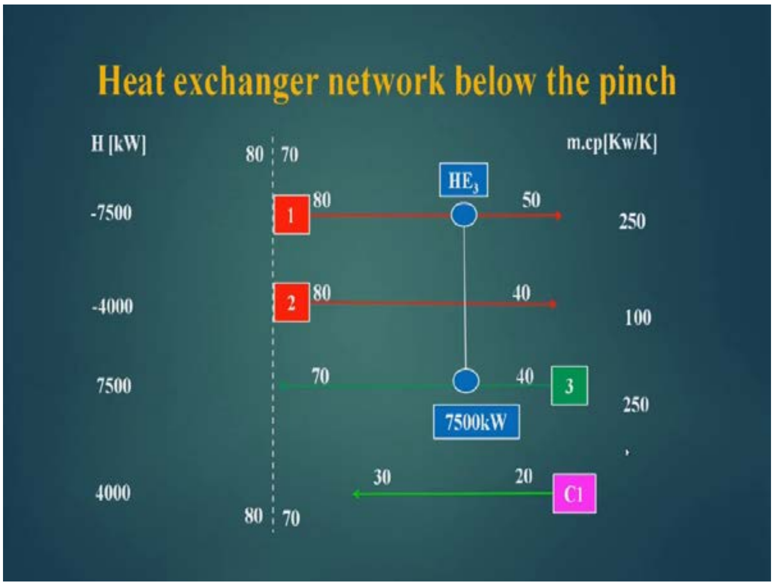

So, if I put that match which is the only available match, this available match is 7500 Kilowatt and this is going to tick off this both streams, because this is 7500 and this is 7500.

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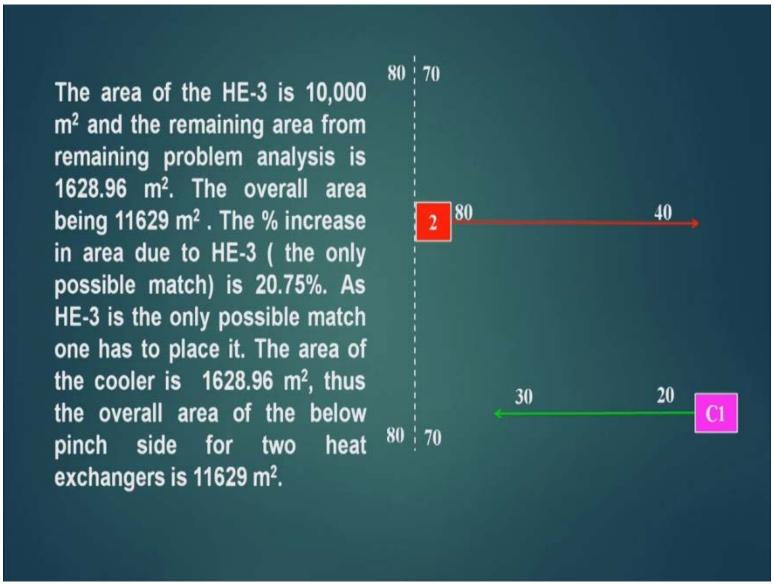

Now, the remaining problem is this, now when I find out the area of the heat exchanger number 3 by the same type of calculations, which has been shown earlier it comes out to be 10000 meter square. And the remaining area for the remaining problem analysis is

1628.96, so area computed for this remaining problem is 1628.96, so the overall area is 11629 meter square.

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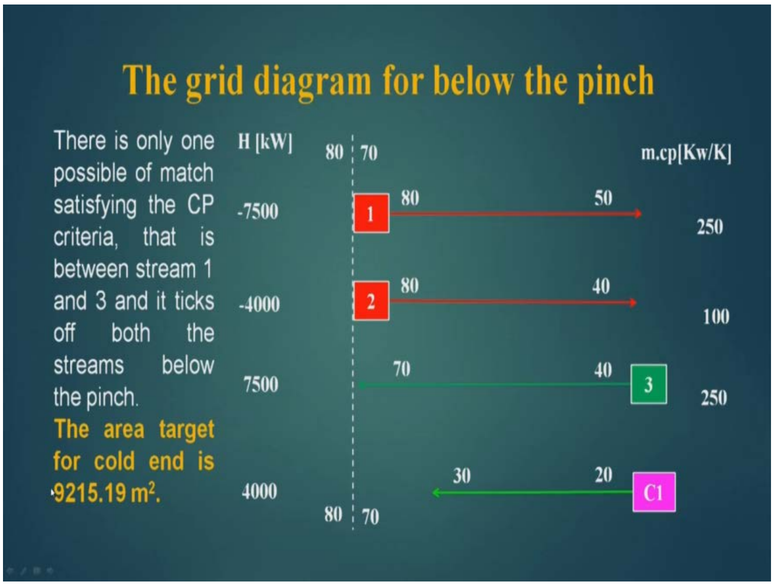

Now, this has to be compared with the earlier targeted value, which was 92154.19 meter square.

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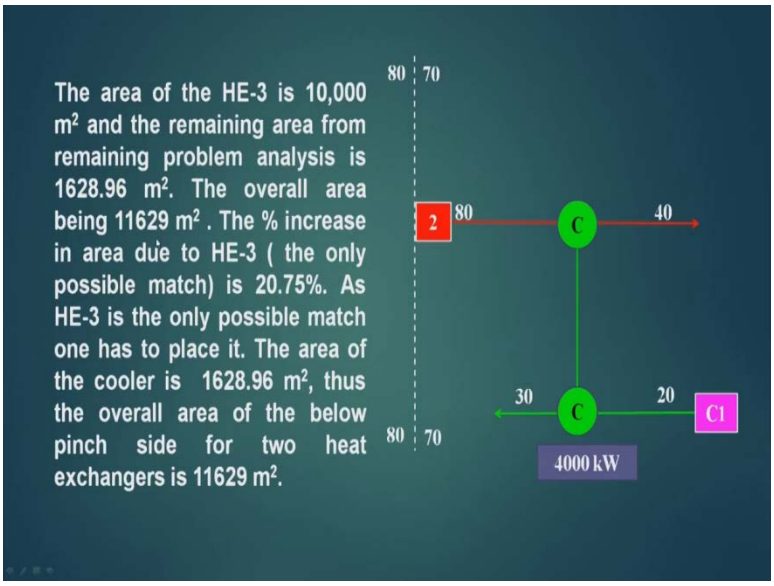

So, what we see there is a considerable increase in the area and if I find out the percentage increase in area due to the only HE-3 the only possible match it is 20.75 percent. And this is a very huge error, huge taxing, but as HE-3 is the only possible match one has to place it, I have no alternative match to select hence I have to exit. Now, the area of the cooler is 1628.96 meter square, thus the overall area below pinch side of the two heat exchanger is 11629 meter square, because the area of this which is 4000 Kilowatt is this.

So, what we have seen that through for this design, we are able to match the targeted amount of hot utility and cold utility, there was no absolutely no problem, but as far as area targeting is concerned. For the hot end design our area increased by 0.4 percent and for the cold end design, it increased by 20.75 percent than the targeted values in the cold end, as there was no alternating match, only there was a single match possible match, and that is why we have to go for it.

And we have to take a loss of 20.75 percent, in terms of area and then wHEN we computed the area of this cooler, it comes came out to 1628.96 meter square; so total area requirement of the cold end is this 11629 meter square.

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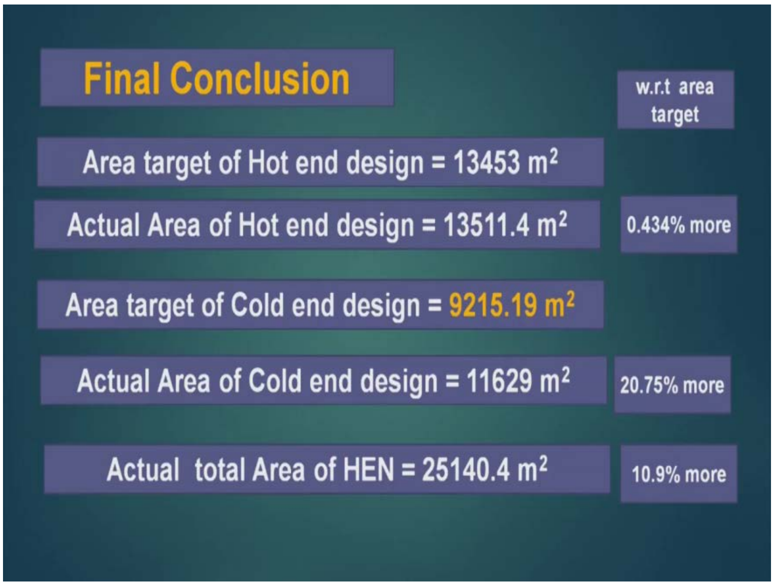

Now, the complete conclusions or final conclusions are this, area target of hot end design was 13453 meter square, actual area of hot end design was on 13511.4 meter square, so it was quite close to the targeted area of hot end. And the error was 0.0434 percent, so the area was 0.434 percent more, the area which we all Z through design, but the situation is not that good for the cold end design, the area target of the cold end design was 9215.19 meter square.

The actual area of the cold end design which came out after the design was 11629meter square which was 20.75 percent more, it is 20.75 percent more, so we can say that we not able to meet the area target for the cold end design. However, we have made the energy targets perfectly for the hot end design, as well as for the cold end design, so the complete design we can say, if I see this error for the total area. So, actual total area of the HEN is 25140.4 meter square and the targeted area will be this plus this, that is 13453 plus 9215.19.

And if I calculate what is the increasing area of the total HEN, then I see that this design is giving 10.9 percent more area than the targeted area. There may be many reasons behind it, that the cold end design is not properly utilizing the available driving force, and that is why the cold end design is offering a larger area. So, this should be investigated, but as far as pinch design rules are concerned and MER design rules are concerned, because this is a MER design. And if I go for the MER design I have to bear this much of loss that means, an increase of area total area of the tune of 10.9 percent, so if I now conclude that what should be my final design or final MER design.

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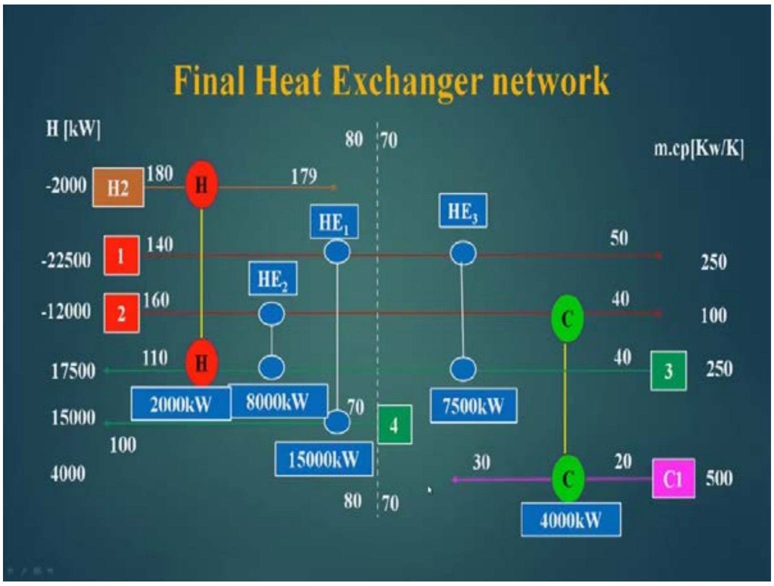

THEN this is my final MER design, so this will have 3 units here and this will have 2 units here, so 5 units and these are the capacities of the units. And we can see that we have very well achieved the energy targets, but we are not able to achieve the area target very clearly.

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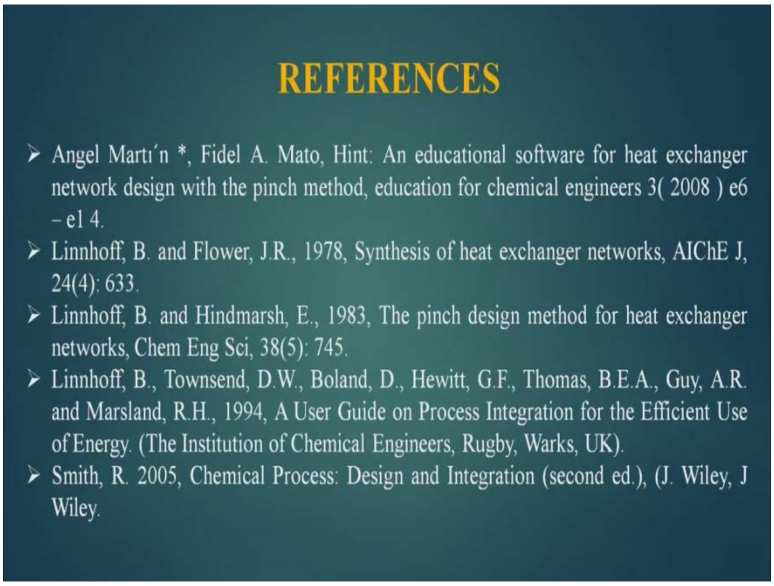

So, these are the references, we have used.

Thank you.