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

Welcome to the lecture series on Process Integration, this is Module 5, Lecture 5, the topic of this lecture is Design of Single Pinch Problem. I have told you that, there are three types of problems are generally encountered, the first one is threshold problems, in which either hot utility is required or cold utility is required, but not both. Then second type of problem is, the hen problems with single pinch, and third type of problem is hen problems with multiple pinch.

The multiple pinch problems generally occur, when we use multiple hot or multiple cold utilities. So, we have divided the design problem into three categories, the threshold problems already we have discussed, how the design can be made, in this lecture we will see, how the design of a single pinch problem should be done. In the single pinch problem also we have divided this lecture into two type of problems, the first in which the stream splitting is not required, and the second where the stream splitting will be required.

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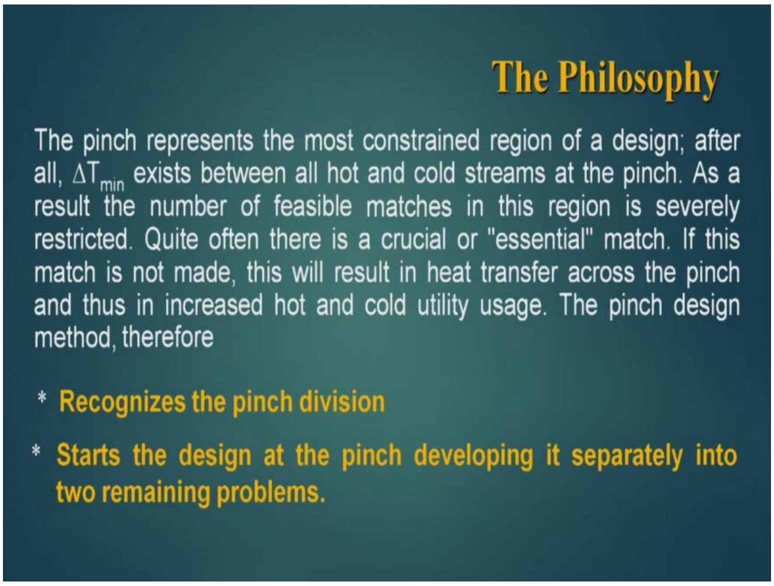

Let us first see the philosophy the pinch represents the most constrained region of a design, this is the most important fact of a pinch design procedure. After all delta T minimum exist between all hot and cold streams at this pinch, as the delta T minimum is small, the heat exchangers which operate near the pinch or at the pinch operate at minimum delta T temperature difference. And hence the area of this heat exchangers are mostly large or high, due to this sometimes the concentration of area of the heat exchanger network, at pinch is high.

And this heat exchangers also contribute towards the total cost of heat exchanger network. And hence placing matches at and around pinch is very important, as a result the number of feasible matches in this region is severely restricted, quite often there is a crucial or essential match. If this match is not made, this will result in heat transfer across the pinch, and thus increase hot and cold utility uses, this we have also explained.

That if there is a passing of heat through the pinch or transfer of heat through the pinch the taxation will be doubled. The cold and hot utilities will increase plus the area required to pass on the additional amount of hot, and additional amount of cold utility will be required also. So, the taxation is double, so placing matches around pinch is very essential, in many a times we will also see in some other lectures that if I am not putting a proper matches at the pinch, the design will not confirmed to the area target results.

And through area targeting generally we reach to the minimum area requirement, and the design will not confirmed to that minimum area requirement. May be that it will show more area than the targeted area, and that is why in the pinch design methodology, we always recognize the pinch division. Because, it divides a bigger problem into two smaller problems as the pinch because, there is no heat flow through the pinch that is why, the upper pinch area or the lower pinch area or we call it hot end or the cold end are separate as far as heat exchange is concerned.

The other rule is that start the design at the pinch developing it separately into two remaining problems. So, design will be started at the point where the problem is most restricted, and then the method is to go away from the pinch because, when we go away from the pinch the delta T increases.

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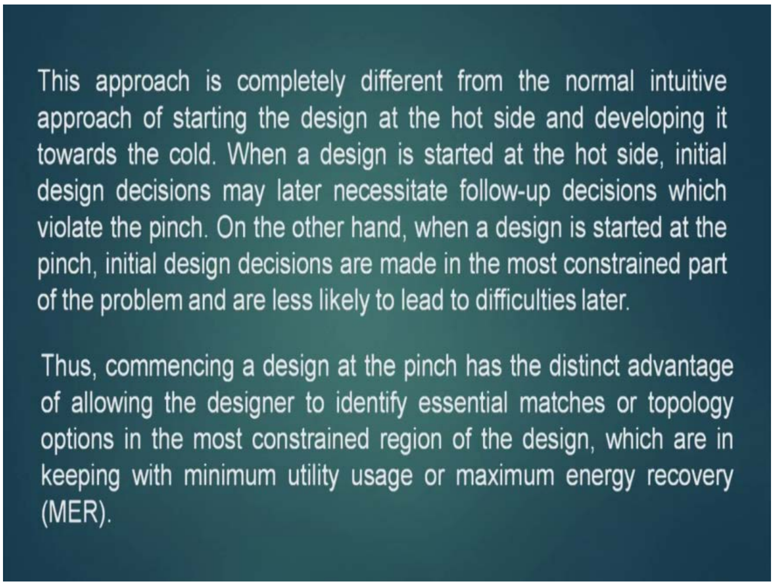

Now, the approach of pinch design is totally different than normal intuitive approach, the normal intuitive approach starts the design at the hot end or hot side. Developing towards the cool side, when a design is started at the hot side, initial design decisions may later necessitate follow of decisions which violate the pinch. So, if we come from the hot side hot end to the pinch, this may be possible that we will violate the pinch; that means, either we will not be able to reach maintain those delta T minimum temperatures.

And if you do not maintain delta T to minimum temperature, we cannot guarantee the hot utility and cold utility requirements. Further this may be possible that the some of heat will passed through the pinch, when we design from the hot side and move towards the pinch. And we know the penalty in such a case is double, on the other end when it design started at the pinch, initial design decisions are made in the most constraint part of the problem, and are less likely to lead to difficulties later.

And based on this philosophy, the pinch design method starts from the pinch where the problem is most constricted, and then moves away from the pinch, thus commencing a design at the pinch as the distinct advantage of allowing the designer to identify essential matches or topology options, in the most constrained region of the design which are in keeping with minimum utility usage, and maximum energy recovery. The maximum energy recovery design will only take place, when no heat passes through the pinch. At the heat passes through the pinch we cannot call it maximum energy recovery design, and in the maximum energy recovery design the requirement of utilities, which consists of hot utility and cold utilities are minimum.

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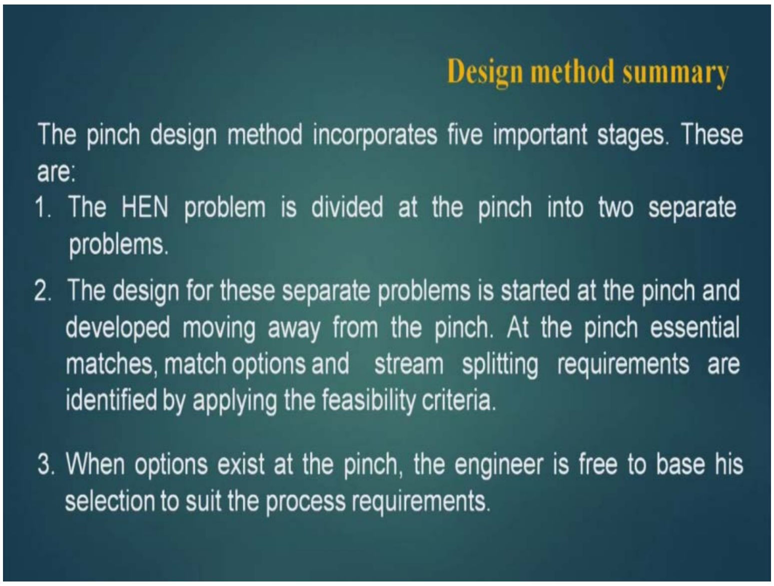

The pinch design method incorporates five important stages, this stages are the hen problem is divided at the pinch into two separates problems. This we know because, no heat process through the pinch, and that is why the upper part of the pinch and lower part of the pinch are can be made separate or they can be designed separately. Because, no heat flows between this two halves, the design of this separate problems is started at the pinch and developed moving away from the pinch this will have explained in detail.

At the pinch essential matches, match options, and stream splitting requirements are identified by applying the feasibility criteria. Then pinch gives some feasibility criteria based on which the matches can be put, they are different for hot end and they are different for cold end. Then whether to go for splitting of a hot stream or a cold stream, are also covered by some rule and regulation.

When option exist at the pinch, the engineer is free to base his selection to suit the process requirement. The pinch design method allows the designer, and offers the designer a lot of flexibility, and according to the process requirements the designer can place a pinch heat exchanger; that means, the stream matching can be done, based on the process requirement by the heat, by the engineer.

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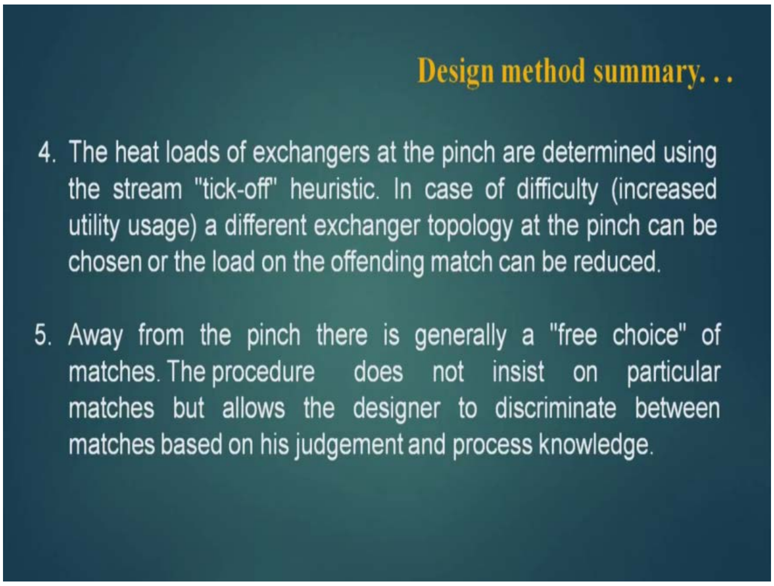

The heat load of exchangers at the pinch are determined using stream tick off heuristic, this stream tick off heuristic has it is based on the number of units target. And if you follow tick off heuristic which has been explained earlier, then number of units will be less. And if you do not obey this tick off heuristic, the number of units may be more or it will be more in most of the cases, in case of difficulty that is when we see increased in utilities, it different heat exchanger topology at the pinch can be chosen or the load on the offending matches can be reduced.

Now, based on tick off heuristic many problems can arise, and to solve those problem we can select different matching's or we can reduce the load of the particular heat exchanger, which the tick off offers. Now, away from the pinch there is generally a free choice, why it, so because, at the pinch the delta T minimum is minimum or delta T is minimum at pinch. But, when we go away from the pinch towards the hot end or towards the cold end, then the delta T available between the hot streams and cold streams increases.

That means, it we can say it is diverged out from the pinch, the diversion takes place with a both the streams diverse out and hence the delta T increases. Once the delta T increases, then it is easier to put matches because, it will not violate the delta T minimum criteria, there we will see that away from the pinch the binding of rules and regulations which are CP rules and streams rules. At least CP rules can be violated to some extent, till delta T minimum violation does not take place.

So, from away from the pinch we can somewhat dilute this CP rule, this we have seen many a times. But, if we dilute the CP rules for pinch exchangers then we will certainly violate the delta T minimum criteria, but if it is not a pinch exchanger and it is away from the pinch, then violating the rule to some extent that is CP rule to some extent, will not violate the delta T minimum criteria. But, in two case we can violate the delta T minimum criteria in the design why because, if I violate the delta T minimum criteria in the design the my hot utility requirement and cold utility requirement to change. When we design a heat exchanger network it is for a fix amount of cold utility and hot utility in aimer design specially. But, when we go for non aimer design, the hot utility and cold utility may increase or decrease now it will not decrease it will increase.

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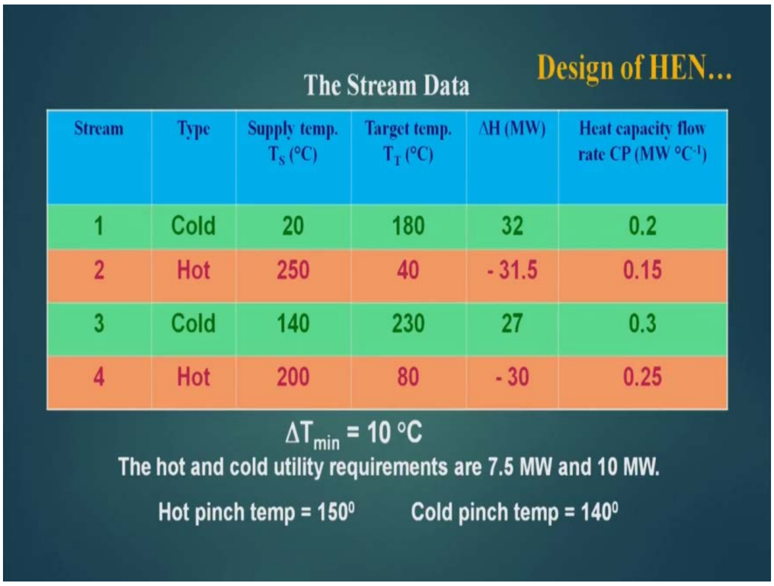

Design of HEN…

The Stream Data

Stream	Type	Supply temp. T_S (°C)	Target temp. T_T (°C)	ΔH (MW)	Heat capacity flow rate CP (MW °C^{-1})
1	Cold	20	180	32	0.2
2	Hot	250	40	- 31.5	0.15
3	Cold	140	230	27	0.3
4	Hot	200	80	- 30	0.25

ΔT_{min} = 10 °C

The hot and cold utility requirements are 7.5 MW and 10 MW.

Hot pinch temp = 150^0 Cold pinch temp = 140^0

Now, to demonstrate this design principles, we have taken a stream data here there are two cold streams, and two hot streams supply target temperature delta H values, heat capacity flow rate ratio are given. The negative sign with the hot streams shows that the stream can give heat, and the positive signs for the delta H columns shows that the streams will take heat. So, with the cold we have positive sign of delta H and with hot we have negative sign of delta H.

The m CP values which is capitals CP are also given for this stream table data, now once we use this steam table data and do the p t a analysis problem table analysis. Then we find that, the hot utility requirement is 7.5 mega volt and the cold utility requirement is

10 mega volt. The delta T minimum for this problem is 10 degree centigrade, and the hot pinch at 150 degree centigrade, and cold pinch is at 140 degree centigrade, and difference between the hot and cold pinch temperature is 10 degree is equal to delta T minimum.

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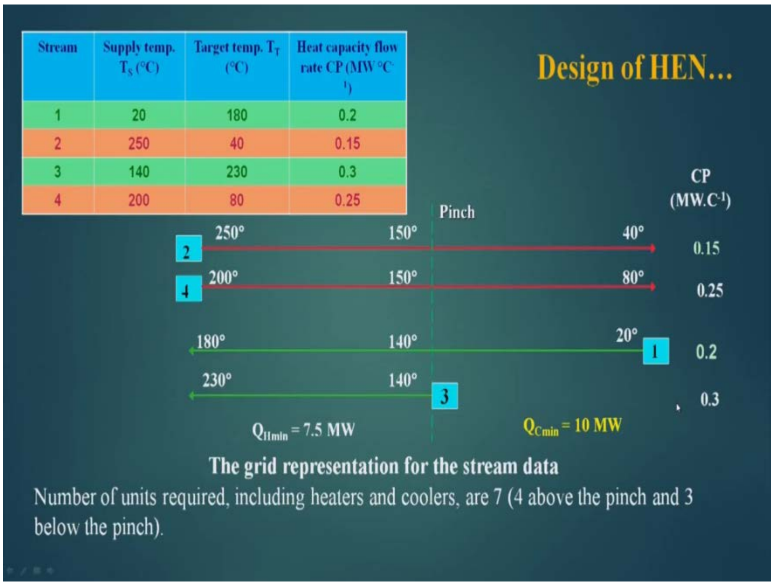

Now, let us convert this stream data into streams lead diagram, so the first stream has come from 2, this is 250 to 40 degree centigrade, and hot pinch is 150 CP value is 0.15. This 4'th stream which is the hot stream start from 200 centigrade goes up to 80 degree centigrade, hot pinch temperature is 150, CP values capital CP values is 0.25, then cold stream one it goes from 20 degree to 180 degree, the cold pinch temperature is 140 degree, CP value is 0.2. And 3'rd stream which start from pinch temperature, goes up to 230 centigrade and CP value is 3 0.3.

So, here we see that in the hot end there are 4 process streams plus one utility will be required, where as for the cold end there are two hot streams, and one cold streams, and one cooling utility. So, this is the stream or lead diagram and we have to design a heat exchanger network for this, now Q H minimum is 7.5 mega volt this is from p t a and Q C minimum is 10 mega volt this value is also from p t a. So, under this constraint our aim is to develop a heat in exchanger network, which will not violate this.

The number of units required including heaters and coolers are 7 because, if I put the number of unit targets here, this is two hot, two cold force stream plus 1 utility 5 minus 1 is 4. And here there are three stream plus one utility that is 4 minus 1 is 3, so for this three units are required and for this 4 units are required, which includes heaters and cooler as well. So, total number of units are 7 for this problems, so we predict the number of heat exchangers for this problem as 7, and this has to be matched through our design. So, we have to match Q C minimum, Q H minimum, numbers of units and this temperature should start with 250 and reach 40. So, these terminal temperatures and the supply temperature has to be matched, and this flow rates has to be matched.

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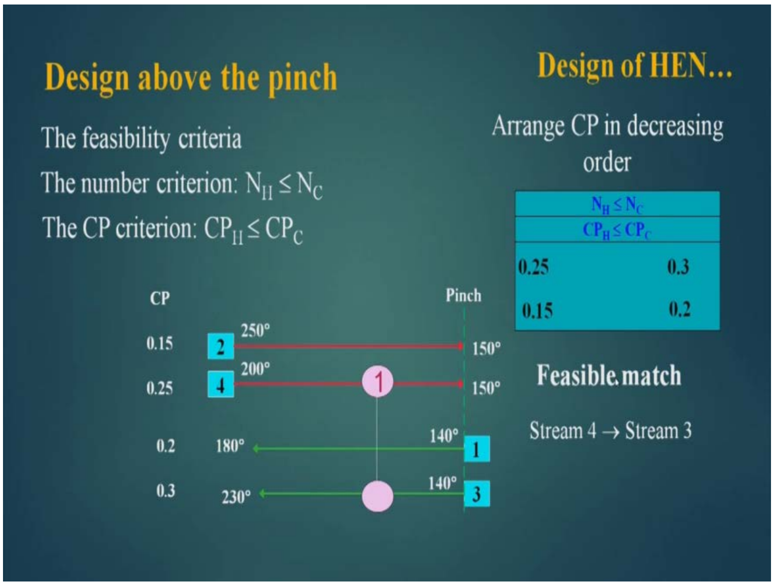

Now, the feasibility criteria for the above the pinch area, which is called hot end or N H should be less than or equal to N C. Now, here we have N H equal to N C, so this criteria is met, now let us see the CP criteria, CP criteria tells that CP H should be less than CP C and this criteria will use, when we put matches. Now, we create a CP table, so here this is for hot streams and this is for cold streams and these are the rules, and based on these rules specially this rule becomes this is valid already, so based on this rules will now put up matches.

So, first match we put from stream 4 to stream 3, now if you see this stream 4 it is CP value is 2.5 there this is and 3 is the this 0.3 this 3. So, there is the match between these two, now if I doing matches between these two CP C is more than CP H, and hence this match is valid. And while discussing CP rule, we have seen that if we obey the CP rules there is no question of delta T minimum violation. Because, the temperature profiles will diverge and it will never converge, and base on that CP rules have been created, so we put a match between this and this. Now, the match should be put in such a way that one stream should be ticked off, now second match we have put between this 0.15 and 0.2 this is 0.15 and 0.2 this also obeys the CP criteria. And hence this match can be put up, so there is no violation in putting of this matches.

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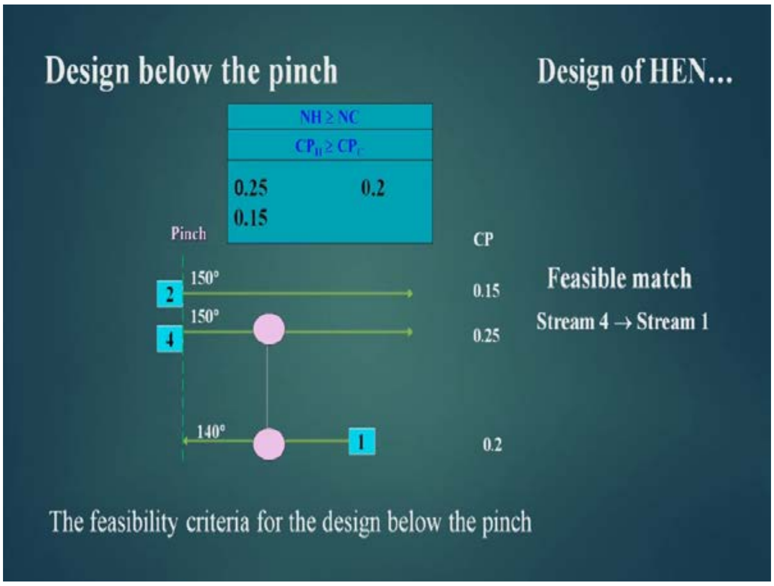

Now, in the below pinch we have these streams, stream number 2, stream number 4, and this is cold stream number 1, CP balance are 0.15, 0.25, 0.2 3 number streams is off here because, three number stream is only present at the hot end, it is not present at the cold end. So, we have this CP table here, and we have to obey these rules these are the reverse rules of the hot end; that means, NH is now greater than or equal to NCm and CP H should be greater than or equal to CP C.

Now, if I put this rule NH is greater than or equal to NC I find that NH is 2S number of streams and N is 1 number of streams. So, this criteria is satisfied here NH is greater than NC, now we can put up a match between stream 4 and stream 1, this stream 4 has CP value of 0.25, and stream 1 has 0.2, so 0.25 to 0.2, so CP H is more than CP C. So, this match is correct, so this is how we will put up matches on the above pinch area and below pinch area.

So, once we have learn how to put matches, then we will directly put matches into the problem, grid diagram and create the total end design. Now, to find out the size of the units; that means, capacity of the units, how much heat it will transfer we will use the tick of heuristic, while putting matches it is required to obey the CP rules specially for pinch heat exchangers. But, the size of the unit will come out by using the tick off heuristic, so let us see how to fix up the size.

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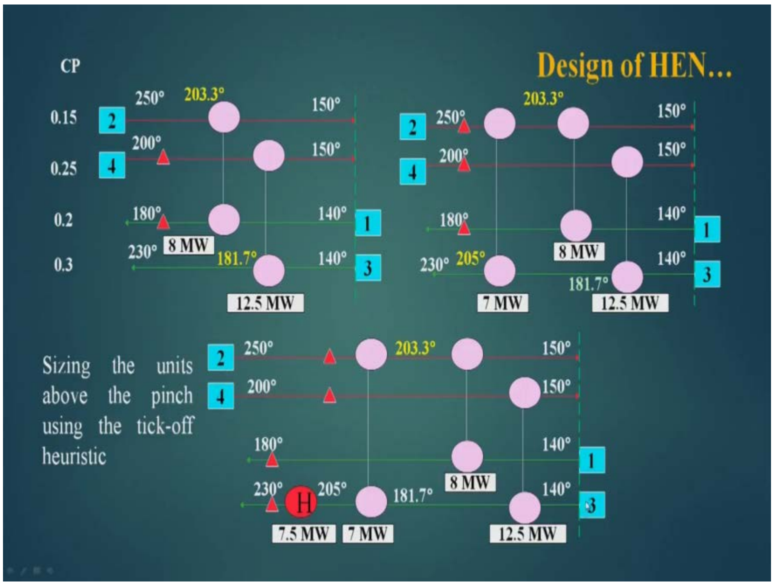

Now, suppose I am putting up this match 4 to 3 this is in the hot end if I put 12.5 mega volt, then this stream is ticked off. The match will be put in such a way that either this stream will be ticked off or this stream will be ticked off, now in this case the hot stream is ready to give 200 minus 150 into 0.25. That means, 12.5 mega volt it is ready to provide, and the cold stream which is 3 is ready to take 27 mega volts, so the total heat available with number 4 streams can be given to number 3 stream it can take.

So, that the 4'th number stream is ticked off by doing, so and fixing of the size of the unit, and also decreasing the number of units; that means, I will move towards number of units target. Now, once I put this, this 140 degree centigrade with raise to 181.7 degree centigrade, and this temperature will be maintained; that means, this will be reach to 200 centigrade. And the input this is the input will be 200 degree centigrade and output will be 150 degree centigrade, cold and this is input is 140 degree centigrade output is 181.7 degree centigrade.

Now, the second match is such that either this will be ticked off or this will be ticked off, now if I find out the enthalpies associated with 1 this 180 minus 140 into 2.2. So, it comes out to be 8 volt, so this stream this is first stream is ready take 8 mega volt, where as the number 2 stream, which is the hot stream is ready to give 15 mega volt. So, the hot stream is in a position to satisfy the requirement of this cold stream mass, so it passes 8 mega watt directly to this, and hence this will be now ticked off this will be now ticked off.

Now, if I consider this as a output temperature from this, then the input temperature of this will be 203.3 degree centigrade I can do the back calculation. Now, as the stream is ticked off and as the stream is ticked off I do not have to bother about these two streams; however, this stream has got some heat available, and this stream is ready to take some heat. So, let us see with I can put a 3'rd match or not, so 3'rd match is between this and this because, this is ready to give heat, and this is ready to take heat.

Now, if I this has got 7 mega watt of heat left with it, so it can directly pas the remaining heat that is 7 mega watt after transferring this it can directly pass to this, so that this will be ticked off, so this is ticked off now, and the temperature after passing this raises to 205 degree centigrade. That means, the input temperature to this is 250 degree centigrade, the output from this is 203.3 degree centigrade, input to this is 203 degree centigrade, and output to this is 150 degree centigrade.

Similarly, the input to this is 200 centigrade, output is 150 degree centigrade the input is 140 degree centigrade for this part, and output is 180 degree centigrade once I pass this it is 205 degree centigrade. Now, this stream needs to be heated up from 205 degree centigrade to 230 degree centigrade, and this will be done by the hot utility, so this is the scenario with us. So, we put a hot utility here of 7.5 mega volt, and this we can calculate 230 minus 205 equal to into 0.3, so it comes out to be 7.5 mega volt.

So, if I pass 7.5 mega watt here, the temperature will rise from 205 degree centigrade to 230 degree centigrade. So, now, this stream will be ticked off, so we see that all the 4 stream have been ticked off, and we have used 3 heat exchanger and 2 heaters if I use the units criteria on this, then 2 stream plus 1 hot utility becomes 5 5 minus 1 is 4. So, here if we count the number units this is 1, 2, 3, 4, so this 4 number of units are inclusive of heater.

So, we have reached to the targeted value of units, our hot utility requirement is same as 7.5 targeted earlier, all streams are starting with their supply temperature and reaching to the pinch temperature, so this design has been completed. Now, hot end design we have completed we will go to the cold end design.

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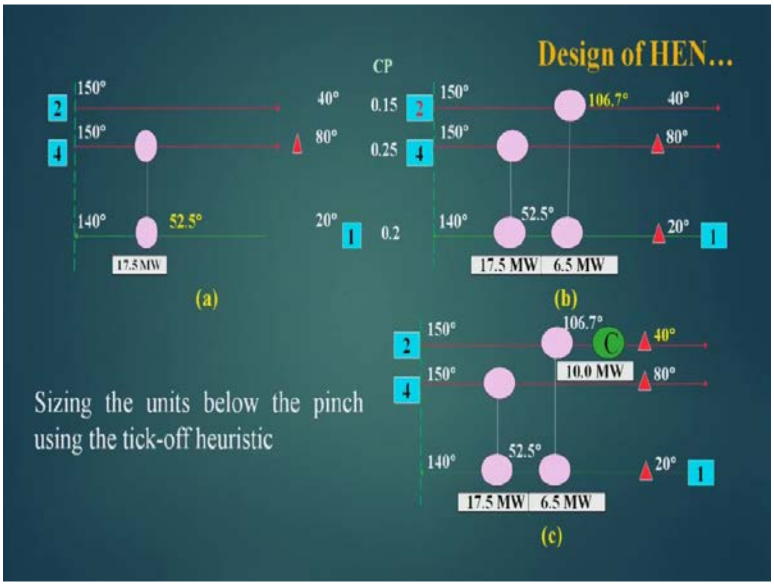

Now, this is the cold end scenario the grid diagram, so we have can put a heat exchanger between these two, and it is value will be 7.5 how, if you see here 150 to 80 this is 17.5. So, this hot utility has 17.5 mega volts, so this can completely give to this cold utility because, it is ready to take more than that, it can take 24 mega volts, so the total heat available with this can be directly given to the this, and we can tick off this stream number 4 is ticked off, now the second match is between this and this.

Now, we have if you add 17.5 plus 6.5 it comes out to be 24 because, this cold utility is able to take 24 mega volts. And this hot this not cold utility this cold stream is able to take 24 mega watt, and this hot stream has already given 17.5 mega volt to this, so remaining 6.5 mega watt will come from this stream because, this stream is already ticked off. So, it passes 6.5 mega volt from this stream, and this is ticked off.

Stream number 1 is ticked off, now if we see the capacity of this hot stream it is 150 minus 40 into 0.15, so this is 16.5, so 6.5 I have already given. So, if I minus this 6.5 it remains 10 mega volt, so once this load is put this temperature 150 drops down to 106.7, but this has to be further drop to 40 degree centigrade. So, you need some sort of heat exchanger here with 10 mega volt of capacity, so we will put a cooler here of 10 mega volt capacity and if we do, so this will reach to 40 degree centigrade, and this stream is ticked off.

Now, all these 3 stream are ticked off, and from pinch temperature all this 3 streams have reached to their target temperature, this is 2 target temperature, and this has reach to the supply temperature plus the cold utility requirement by the p t a has been reached. That means, the cold utility target has been achieved, now let us see that number of utility target has been achieved or not. So, this is 3 streams, 1 cold streams 4 minus 1 is 3, so here we see 3 heat exchanger including the cooler. So, we have match the hot utility and cold utility requirements, and we have also match the hot utility requirement sorry the number of units, in upper pinch as well as lower pinch area.

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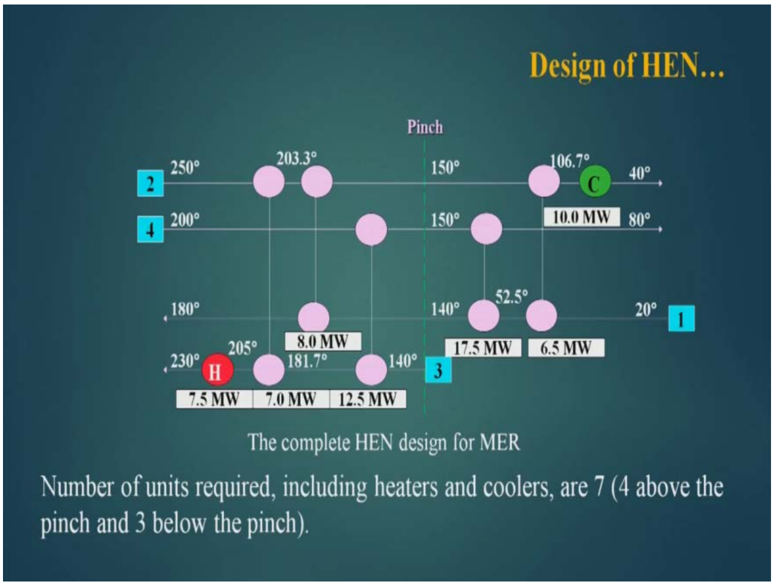

So, my complete design is this, so this is the complete design of the heat exchanger network for the problem given, and they are get table. And here there is only single pinch available, now we see a second problem which is called design of hen with stream splitting, in the earlier problem there was no streams splitting, but in this problem we will see some stream splitting.

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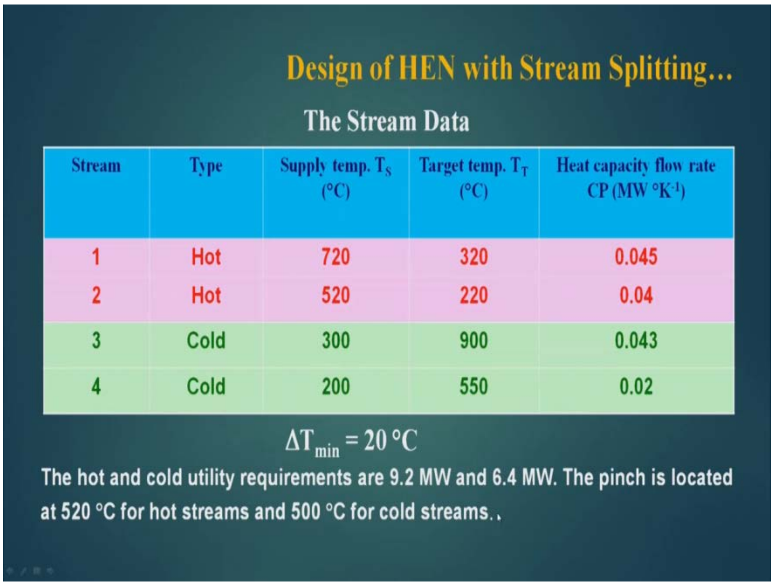

Now, this is the stream data which will be used to exhibit streams splitting, there are 2 hot streams, 2 cold streams. And the CP value is this the delta T is minimum 20 degree centigrade, the hot and cold utility requirements are 9.2 mega volt, and 6.4 mega volt this has be done from p t a, the pinch is located at 520 centigrade for the hot stream, and 500 centigrade for the cold stream, the difference being 20 degree centigrade equal to delta T minimum.

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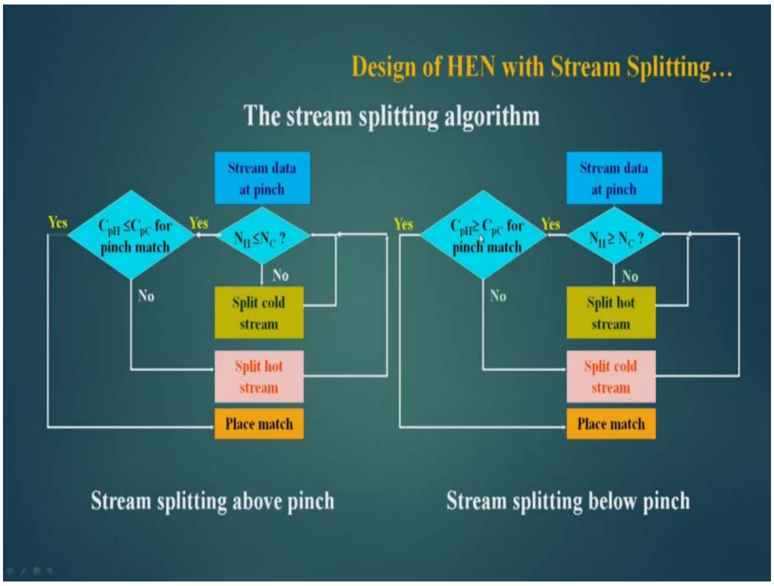

Now, this is stream splitting algorithm for the above pinch area that is hot end, we to have take the stream data at the pinch, then check whether NH is less than or equal to N C. If no then we will split a cold stream, so that the number of cold stream increases, and we will still doing we will continue doing, so when this is matched once this is match we will go to CP matching, and will check this. If yes then will put a match, place a if no then will split a hot stream, and again will go via this.

That means, we will check this criteria whether this criteria is met or not, if it has violated then we will again split a cold stream. This will go on when this criteria is matched, and then yes we will go here and we will put a match, similarly for below pinch this is the criteria. Now, this is the same way I can explain this, but here you notice that, this is different than this sign has been reversed, and similarly this sign has been reversed here.

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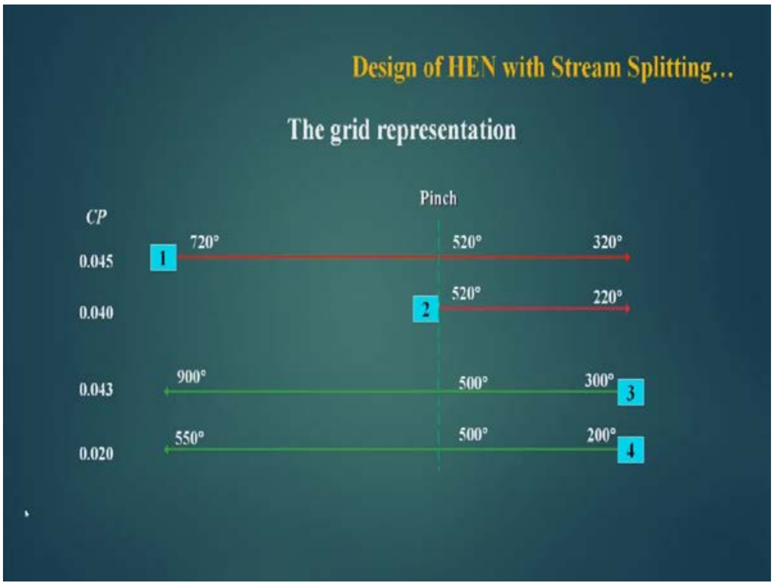

So, this is the grid diagram these are CP values, here we have at the cold end we have four streams and the hot end we have 3 streams.

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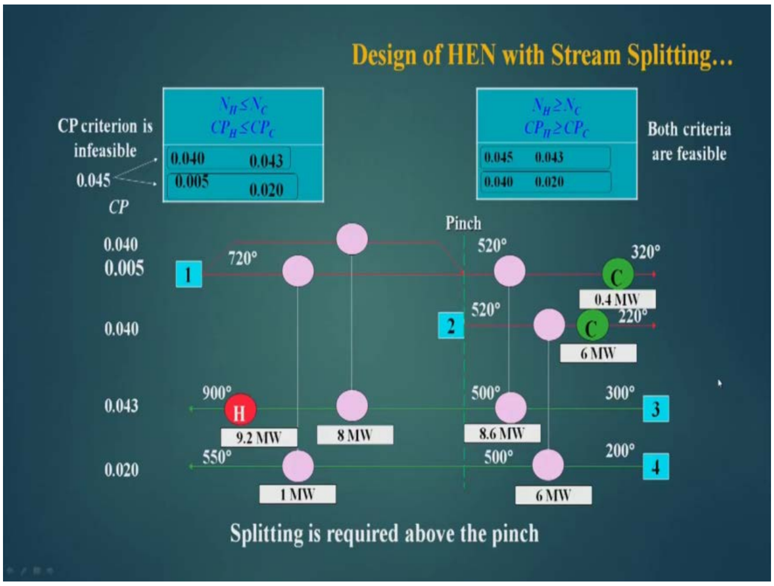

Now, this is the table first we will go for the hot end, here N C should be greater or equal to NH, here N C is 2 and NH is 1, so this is satisfied. Now, let us take this the CP table, CP C should be greater than CP H, but we find here none of these 2 CP's are greater than this. So, we have to go for a splitting, CP criteria is infeasible that is I am not able to apply this CP criteria for place making or the pair making, now here we see this, so NH is equal to N C, so this criteria is fulfilled, CP H has should greater then CP C, so this criteria also fulfilled.

So, both criteria are feasible here, so I do not have to bother much here, but here I have go for splitting. So, splitting is required above the pinch, so 0.4 has to be spitted into two parts, one part is 0.040 and the other part is 0.005, now I can put the match, so this is the splitting which we have done there is one extra branch here. Now, this is 0.4 and 0.5; that means, this branch is 0.4 CP, and this branch has got a CP of 005, now this matching can be done 0.004 to 0.043 and 0.005 to 0.020 because, both CP’s are more than this CP’s.

So, we put a match here of 8 mega volt and the size of this match will be based on tick off heuristic. And we put a match of 1 mega watt here, and then we put a heater 9.2 mega volt, now we can calculate here if this is from 500 to 550 by 550 to 500. So, this is 50 into 0.02 which comes to be 1 mega watt, so this stream is ticked off because, it requires 1 mega volt. Now, if I see this part this is 720 to 520 720 minus 520 into 0.04 comes out to be 8 mega watt; that means, this stream has a capacity capability to give 8 mega watt.

So, completes capability of the stream has been passed on to this 8 mega watt, so this is ticked off and this part is ticked off. Now, the total capacity of this is 720 minus 520 equal to this 200 into 0.045 to 0.045 which is 9 mega volt, so by passing heat of 1 mega volt to this, and 8 mega watt to this, this is ticked off and this is ticked off. But, the requirement of this stream is more than 8 mega watt, so requirement is 900 minus 500 into 0.043 it comes out to be 17.2 mega volt.

So, you have already passed 8 mega volt, so requirement is another 9.2 mega volt, now as all the heat has been given by the hot streams, no heat is left in the hot end. So, the heat has to be brought down from the utilities, so the rest 9.2 mega volt has been pass to this from the hot utility. Similarly, we can go design for the cold end we can put a match a match here of 8.6 mega volt, then we see that this is 5.20 minus 320 into 0.045 comes out to be 9 mega watt.

So, 8.6 mega watt it has given to here and what is the requirement of this, 500 minus 300 into 0.043 this is 8.6 mega volt. So, this requires this stream number 3 requires 8.6 mega volt it can give more, so it has passed 8.6 mega watt to here and this has been ticked off. So, the second match is, but this was left out hot streams, so this second match is between this and this, which is between 0.042 to 0.02 and this both meets the criteria CP H or greater or equal to CP C.

Now, let us check here this 500 minus 200 into 0.02 comes out to be 6 mega volt, so the heat taking capacity of this heat observing capacity of this stream cold stream is 6 mega volt, so this is ticked and this is ticked, this is also ticked. So, we need a cooler, so 2 coolers are put here because, this can has a capacity of 520 minus 220 into 0.04 12 mega volt. So, out of 12 mega volt it has given 6 mega watt to here and it has ticked of this and this has given 8.6 mega volt to here, this has ticked of this, this has capacity to give 9 mega volts.

So, 0.6 mega volts will come from cooling water it has to be cool down by 0.4 mega volt, and in this case 0.6 mega volt will from the cooling water. Because, no cold stream is a available because, this two are ticked off no cold stream is available to cool it, so this is the capacity of my cooler now total capacities 6.4 mega watt.

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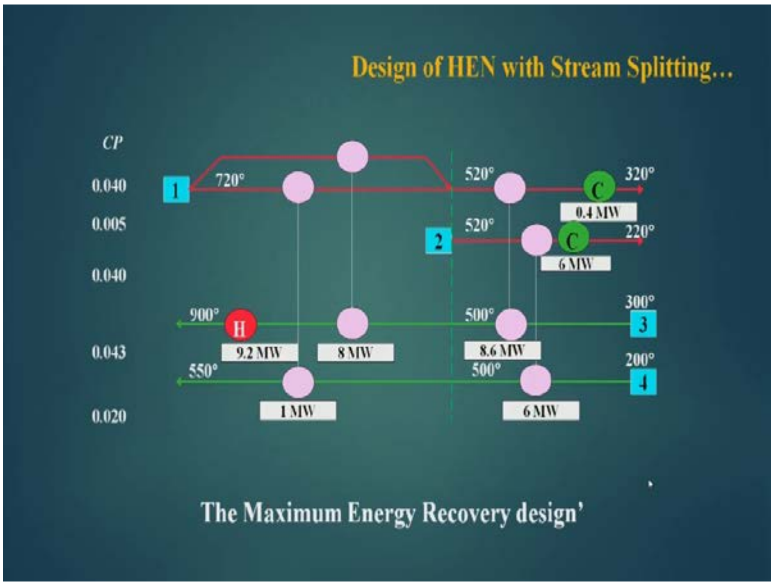

So, this is my complete design and this is called a maximum energy recovery design.

Thank you.