Process Integration

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Module - 7
Tutorial & Case Studies
Lecture - 4
Problem solving using HINT Software-Part 04
Remaining problem analysis
Driving force plot

Today I shall start a new topic which is remaining problem analysis, this is used during the design of hint now while placing heat exchanger many times. We have more than one choice and we use this choices sometimes. We find that the choices are taxing the heat exchanger area; that means, the area is increasing and it is becoming more than the minimum area computed by area target. So, out of the available matches we should only select those matches which will not increasing the minimum area calculated by the area target.

Now in this way the remaining problem analysis helps the design to guide the placement of the heat exchanger in above and below reasons a pinch. So, that the targeted values computed by the targeting procedures are not increase to a large extent the targeted values. In this case are energy target number of units target area target and the cost target and this can be used for remaining problem analysis.

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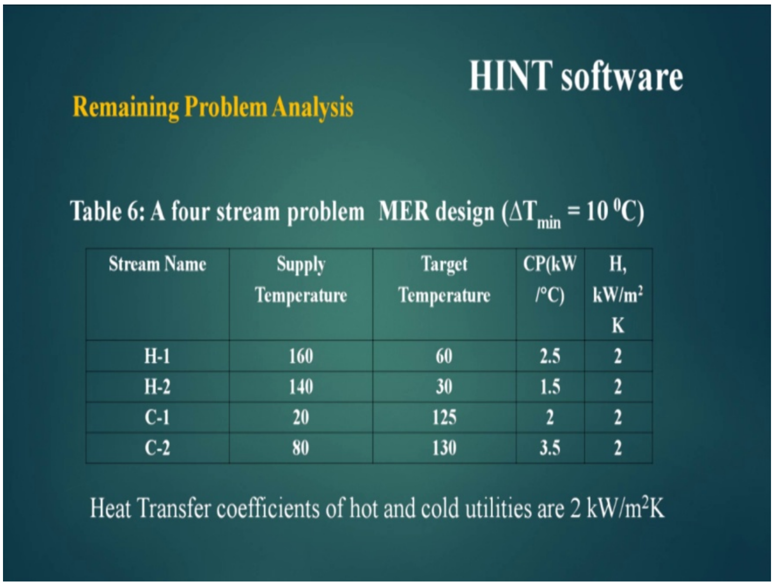

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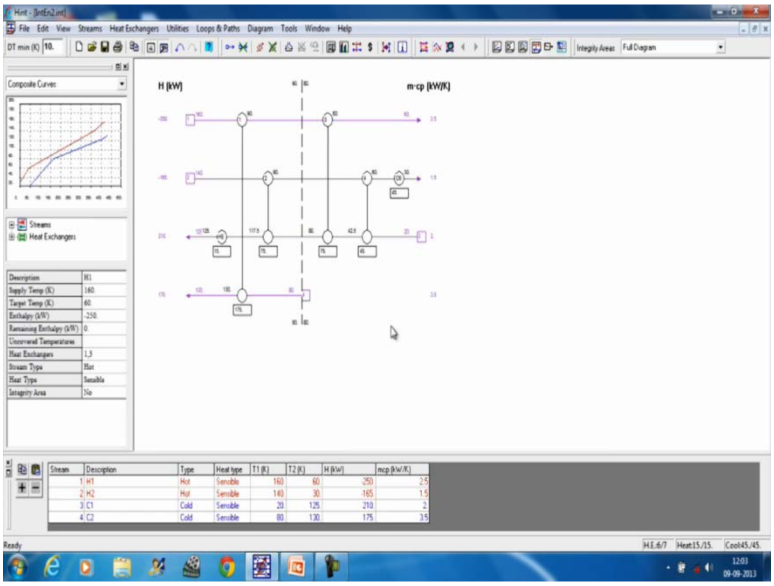

Now let us see it through an example which is given in table six a four stream problem, which we have also taken earlier and apply this remaining problem analysis to this. So, we start a new problem. So, we add streams h1the supply temperature is 160 the target temperature is 60 and m cp is 2.5. This is necessary to start the problem form the beginning because then only will be able to show the concept of remaining problem analysis H2 140 30. And this is 1.5 add this is C1 this is 20 the target temperature is 125 then m cp value is two C2 80 130 and 3.5 I am using the default values of hot utility and cold utility given in the software hint. It is also possible to define this utilities and do the remaining problem analysis.

So, this is the grid diagram which I get for this stream table now we have to place heat exchanger. So, the first heat exchanger we place because the first heat exchanger is a pinch exchanger we go via this route feasibility above pinch. So, here the m cp hot stream is less than m cp cold stream. So, this can be merged with this, so I place a heat exchanger. Now once I place a heat exchanger here then I have to go to the heat exchanger drop down menu and place the remaining problem.

Now this dialog box opens it tells that the minimum heat number of heat exchanger is seven I have installed one heat exchanger and the remaining is five. So, five plus one is six and here it is seven we have to understand why this has happen here. In this problem there is a subset equality and that is why the number of heat exchangers will be seven minus one equal to six and that is why it is showing six heat exchangers. Now tells that the minimum area required using the area target is 21.9533 I have installed one heat exchanger it is area is 9.61286 and the area of the remaining five heat exchangers are estimated to be 12.4024. If I add this two quantities 9.61286 and 12.4024 it becomes 22.0152; that means, the total value has exceeded the minimum area required by a little bit in the after finishing this problem. We will see that in a tabular form that how much area has increased.

And why I have accepted that match here, you see that there are four things given area capital cost heating and cooling this four quantities can be used for the remaining problem analysis. However, I am only using the area part of it to demonstrate the remaining problem analysis you can use any of this four to the remaining problem analysis.

Now I put the second heat exchanger, so again the second heat exchanger is a pinch heat exchanger. So, it can be easily put through this, so this and this active this. So, this is the second heat exchanger. I have put now after I have put the second heat exchanger again I will go to the heat exchanger menu go to the remaining problem this dialog box opens now here the area target. Remains the same, but installed are two heat exchanges and the total area consumed by this two heat exchangers are 14.4784. And the four the area of the remaining four heat exchangers are 7.5368 and the total is 22.0152.

So, the total has not increased almost remain same as before. So, we can accept this heat exchanger. Now we go to the stream feasibility below pinch, and here the m cp hot should be greater than m c p cold. So, I come to match this and this I can put of a pinch heat exchanger also then again I go to the heat exchanger menu remaining problem analysis. And open up this dialog box it is says that area target was 21.9533 unchanged, it would remain unchanged. We have been installed three heat exchangers and the area combined area of all the three heat exchangers 20.0746. And the remaining three are 3.02272 the area has increased the little bit to 23.0973 and the increases about five percent or so, but I have nothing no options. So, I have to then I go for the heat exchanger add and put up my fourth heat exchanger between the number two and number three streams.

So, I had fourth heat exchangers, so my cold is number three and hot is number two and the enthalpy of this heat exchanger is 45 my cold inlet temperature is the cold supply temperature and hot inlet temperature is my pinch temperature. So, I say I puts a heat exchanger here, now I again go to the remaining problem analysis. It tells that four heat exchangers have been installed the combined area of the four heat exchangers installed. Heat exchangers are 21.1057 there are two heat exchangers remaining, we know that cooler. And heaters are remaining and the area combined area of those two heat exchangers remaining heat exchangers are 1.99162. And the area is almost constant as before that is 23.0973.

So, we take it ok now will place the heaters and cooler; so, here between this we have to put a heater because the cold stream, which is at 117.5 degree centigrade is to be heated to 117.5 degree centigrade. And we have to use the hot utility for its heating similarly that hot stream, which is at 60 centigrade after the heat exchanger four has to be cool down to 30 degree centigrade. And hence it needs a cooler and we have to use the cold utility. So, let us put the heater here in the stream number three, so again we go to the heat exchanger add here. We use add the swift number then code then cold stream number is three and hot stream is utility and the enthalpy is fifteen. And the cold inlet temperature is one 17.5 say, if I say it puts a heater it puts a heater here. And this heater heats this cold stream from 117.5 to 125 and its capacity is about fifteen kilowatt now we have to put a cooler here.

So, we go to ha yes after putting the heater we again go to the remaining problem analysis here. We have put now five heat exchangers the combined area is 21.2294 and there is one remaining that is the cooler, which area is 1.64972. And the total area combining this remaining and installed is 22.8774. So, we see that it has decreased and hence the increase in the area has also reduced will see that later. So, we can accept this heat exchanger.

So, now, here we have to placed a cooler here we add this we put the add, so is a six number cold stream cold utility will be used and hot stream is number two and enthalpy is 45 and the inlet temperature the hot inlet temperature is 60. So, we place this now we again go to the heat exchanger menu remaining problem analysis we see that here. We have installed six heat exchangers who's combine area is 22.692 whereas, through area target we get 21.9533. And the total area after the design is about 22.2692, which is quite close to the area given by the area target.

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Area computed for (Above+below pinch) using area target: 21.9533 m^2

No. of Heat Exchanger using units target: 07

As there is a "subset equality" the no. of units are: 7-1=6

HX selected	Load, kW	Area, m^2	Total installed area, m^2	Remaining Area, m^2	Total Area, m^2	% increase from area target	Remarks
HX(stream 1&4)	175	9.61	9.61	12.4024	22.0142	0.28%	Match accepted
HX(stream 2&3)	75	4.8655	14.4784	7.5368	22.0152	0.28%	Match accepted
HX(stream 1&3)	75	5.5962	20.0746	3.02272	23.0973	5.2%	Match accepted
HX(stream 2&3)	45	1.0311	21.1057	1.99162	23.0973	5.2%	Match accepted
HX(HU&3)	15	0.1237	21.2294	1.64792	22.8774	4.2%	Match accepted
HX(CU & 2)	45	1.0398	22.2692	0	22.2692	1.4%	Match accepted

N.S.: Not selected

So, this design can be accepted now let us see the analysis part of it, now the area computed for above. And below pinch using area target was 21.9533 meter square number of heat exchangers using units target and when you are calculating this number zero seven number. We have use this units target above the pinch, and the below the pinch and then we have to join the results what we got. So, it becomes seven, but there is a subset equality in the problem; so, subset equality and that is wise the number of units will be decrease by one. So, seven minus one is six and what we saw in the remaining problem analysis that it calculated six units. So the heat exchangers, which was put between stream one; and four which was heat exchange an one as a load of 175 kilowatt and it is area was 9.61.

So, the total installed area was at that time 9.61 and the remaining area five heat exchangers were 12.4024. And the total area was 22.01422, which was .28 percent access or more than the targeted area of 21.9533. So, the match is acceptable in the second match, which was between stream number two. And three which was heat exchanger number two the load of the heat exchanger was 75. And the area was 4.8655 this was computed or this can be taken from the other menus like I will show you here. We can go to the heat exchanger menu we can go for the results and we can go for area and cost here. I find the area of the first heat exchanger then I can go to second here, the area second heat exchanger I can go to third fourth fifth sixth.

So, this way I can have the area of all the heat exchangers, even if I want cost of heat exchanger I can have from here. So, we again go to this, so the area of the second heat exchanger was 4.8655 total installed becomes 14.4784. This shows the area of this heat exchanger plus this heat exchanger. And the reaming were four heat exchangers who’s area was combined area was 7.5368 total area is 22.0152. So, increase is around point two eight percent and hence the match was accepted, when we went for the third match which was between stream one and three.

So, due to the pinch rules we have to accept this match because this was the only match which is feasible. So, its load was 75 the area was 5962 the area of combined all the three. That is this and this was 20.0746 and the remaining area of three heat exchangers were 3.02 to seven two total was 23.0973. Now this showed a five point two increase five point two percent increase than the minimum area, which we got through area targeting, so this increase is considerable.

But we have no option because the pinch rule says, that we have to accept this. And this was further this was a pinch heat exchanges. So, we cannot valet the rule hence we have to accept this. Then we place the fourth heat exchanges this exchanger also this exchanger valeted the pinch rule, but when we compute the delta t minimum it did not valeted the delta t minimum criteria. Hence it was accepted because the pinch rules has to be, if the heat exchanger is a pinch heat exchanger.

So, here when we put the fourth heat exchanger they are comes out to be 1.0311 the total area of all this four heat exchanges had 21.1057 the area of the remaining heat exchanger. In this case that a two heat exchangers remaining the heater and the cooler it combined area is 1.99162 and the total is 23.0973. So, there was a increase of 5.2 percent, but I have no option I have to accept this match then we put the heater and coolers. So, this is the heater this is hot utility and third number of stream. So, its load is fifteen its area is .1237 the total area of this five heat exchanger is twenty one two two nine four and the remaining area that is the coolers area is 1.64792 based on the remaining problem analysis and the total area is 22.8774.

Now, we see that little bit the error decreases to 4.2 percent. So, the match is accepted because no option. And then I put the cooler, which load was 45 that area was 1.0398 and total installed area of all the six heat exchanger is now 22.2692. And there is no remaining heat exchanger; that is why this is zero and the total area is now 22.2692. So, this shows a near increase in the area by one point four percent and hence the match is accepted. So, what we found that after the design the area has slightly increased than the targeted area and this increase is 1.4 percent. Now this shows clearly how the remaining problem analysis can be used.

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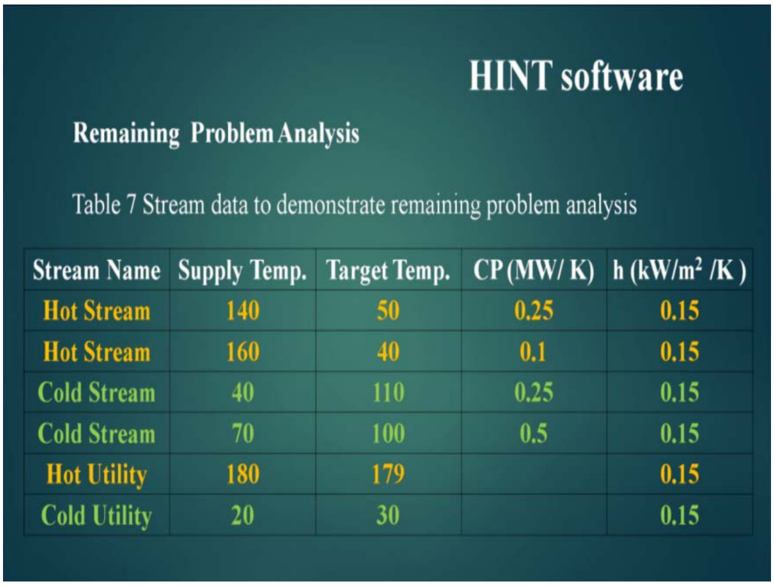

HINT software

Remaining Problem Analysis

Table 7 Stream data to demonstrate remaining problem analysis

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

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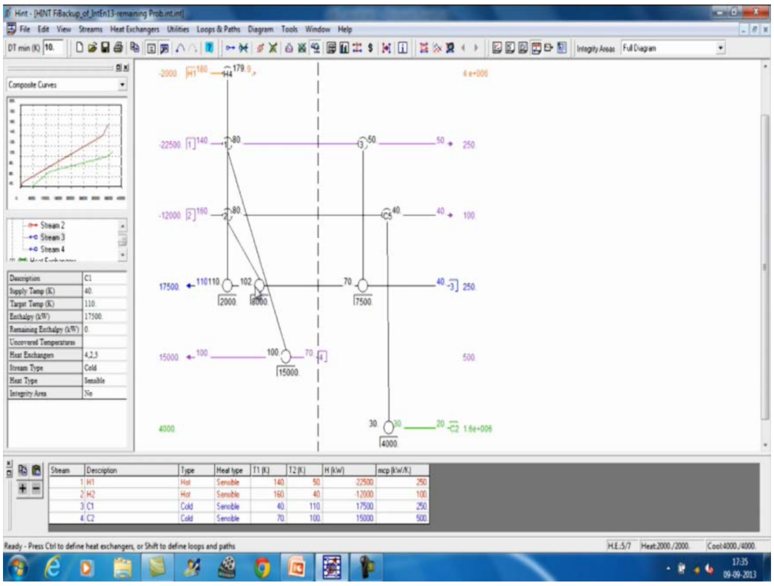

Let us take another example of remaining problem analysis the problem is given in table seven; there are two hot streams two cold streams and user defined hot utility and cold utility. Now if we plot this using the software then we get the stream data like this; this is the user defined hot utility h one hundred eighty two one seventy nine. And this is user defined cold utility from twenty two thirty and these are process streams. Now will apply our process will apply the remaining problem analysis technique for the design of heat exchanger. Now if we go to this streams and feasibility and see the feasibility matches then we see that above pinch there are alternative matches available. There are many options three can be merged with one three can be merged with two four can be merged with one four can be merged with two. When we go for all this alternatives then we find that this alternatives stacks the minimum area targeted area differently. And thus we should select those matches, which stacks the minimum area by area targeting less.

This will see through this example now let us put a match between one and three one and three matches perfectly possible. So, we go to the feasibility above the pinch; and we here see here that one and three matches possible. Because m cp of hot stream should be less or equal to m cp of cold stream this condition is satisfied. So, we put this match now this matches of ten 1000 kilowatt, and if I go to my remaining problem analysis. What I see that are installed one heat exchanger; its heat transfer area is thirteen thousand three hundred thirty three point three my area from area targeting I get area of twenty two thousand six hundred sixty eight point two. And when I place this match the overall area becomes 27824 and if I see this taxing is about twenty two point seven percent. So, this is 22.7 percent more than the area target; and hence this match is taxing a lot and hence it should be removed.

So, I press select this heat exchanger I go to delete heat exchanger number one I delete it. Now the next match I should put between one and four. Because this is a acceptable match one and four this acceptable match perfectly right. So, one and four it also allows me to put that match. So, I put the match, so this match is of fifteen thousand kilowatt. And if I use the remaining problem analysis, so what I find that the match the area of heat exchanger number one is 9241.96 my area targeting gives me area of 22668.2. And the average area is here 22726.6, so it is quite close to the area of the area target. And if I quantitatively find out it is only point two five seven percent more than the area target value and hence this heat exchanger is acceptable and this is a good match. So, we did not go for the first heat exchanger; because it stacks us about twenty two point seven percent. And this heat exchanger is stacking only .257 percent; and that is why we have gone for this?

Now, we put the second match streams feasibility above pinch; now the second match can be between stream number two and stream number three. So, we put a second match now after putting the second match. We can go again to the remaining problem analysis; we find that we have already installed two heat exchangers their combined area is thirty one 131.48.3 area target form area target I get 22668.2. And the remaining four heat exchanger is 9578.28 now the total area is twenty two thousand seven twenty six point six we will fine. That in this problem color two subset equalities are there and hence the number of heat exchangers, which will be installing will be less than the minimum number of heat exchangers seven which has been calculated on the basis of in its target without considering the subset equality.

So, this heat exchanger that is heat exchanger, but two is only taxing me .257 percent; that means, the total area is .257 percent more than the area which has been targeted. So, this is acceptable to me now we go for a third heat exchanger and that third heat exchanger will put here; below pinch and I will like to tell you that if you see the feasibility matches there is only one match available in the below pinch that is stream number one. And stream number three there is no their match, so, I am bound to put this match; so, when I put this match one and three one and three. So, when I put this match one and three I again run the remaining problem analysis. So, all together this three heat exchangers is contributing 23148.3, and there two remaining heat exchanger which are 1992.05.

So, the area immediately jumps up to 25140.4, now this is about 10.9 percent more than the targeted area which is 22668.2, but I have no option. So, I am putting this of this is costing me 10.9 percent more area as have no alternative I am accepting this match. Now then we have to put heaters and coolers, because two heat exchangers are left with so, let us put a heater; which is obviously, to be put between the h1. And this stream number three this because this temperature is hundred two it has to be brought 210 degree centigrade. So, heating is required. So, we go for heat exchanger add heat exchanger hot stream, we go for u one that is user defined hot stream number one the here. I have to select the three that is this stream. And then I go for users applied enthalpy the enthalpy is 2000 in this case and the cold inlet temperature is 102.

So, here I have to go for forth number. So, again I have to change this is u1 this is third this is 2000 this is 102 and then I press. So, let see what has happened again I put the heater. So, add the mistake was that I did not selected it properly. So, this is forth number this is third stream and this is u1enthalpy is 2000 and inlet temperature is 102. So, I put it here. So, this is the heater now if I run the remaining problem analysis, it says that we have already laded four heaters sorry four heat exchangers. And the one heat exchanger is left with and this has become 2400 900 2400 972.4.

Now we put the last heat exchanger, which is C5which is between the cold stream. And this stream number two, so we go to the heat exchanger add menu then we change this to five and this is cold utility u2 and this is hot stream is two and this enthalpy is 4000 and hot inlet temperature is pinch temperature. So, so now if I see this remaining problem analysis; it shows that area is two thousand four hundred two four two one nine. And there are five heat exchanger has been installed and why this is five, because if you see this and this forms a subset. And this and this forms a subset and as there are two subsets available the number of heat exchanges required is now seven minus two which is five.

So, we get five heat exchangers here. So, what we conclude that and this area, if we see we can calculate 24219 minus 2268 divided by 22668 the heat is about 6.8 percent more it is about 6.8 percent more. So, we have to be here with this 6.8 percent more area for this heat exchanger. Now, what we observed from here that the remaining problem analysis in a complex situation helps us to place the proper matches, which will not tax the area of the heat exchanger network.

Now, I will explain what is the role of driving force plot? We have see that if we have absence for different matches. And we exercise this option the area of the heat exchanger network changes; now the question is why it is changing if we start proving this question then will find that different heat exchanger networks utilities the driving force. Which is available for heat exchange in different ways; that means, if I consider available driving force is hundred percent then some network may utilize ninety percent of heat and some other may seventy percent of heat. So, if a network is utilizing seventy percent of driving force its area will be higher if it is utilizing ninety percent of the driving force the area will be less.

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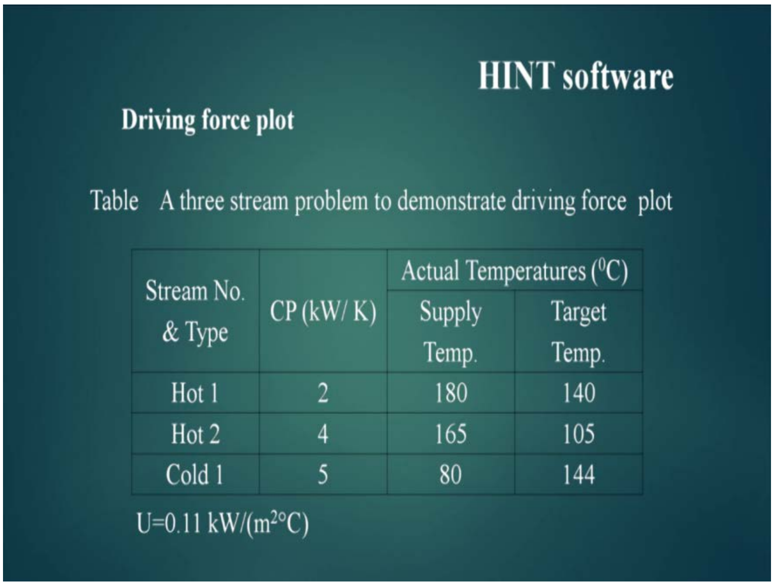

Stream No. & Type	CP (kW/ K)	Actual Temperatures (°C) Supply Temp.	Target Temp.
Hot 1	2	180	140
Hot 2	4	165	105
Cold 1	5	80	144

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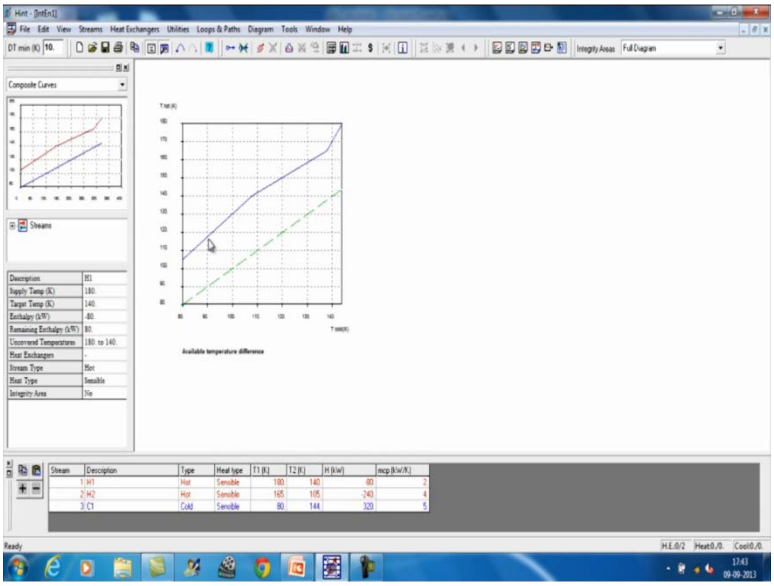

So, different heat exchanger network design offers different area this we will try to understand through a small problem. So, this is the problem we will take a three stream problem to demonstrate driving force plot two hot streams and one clod stream. So, we go to stream add this is h1 supply temperature is 180 and target temperature is 140. And m cp value is two add h2 supply temperature is 165 target temperature is 105 and m cp value is four add C1 supply temperature is eighty and target temperature is 144 and m cp value is five.

Now this is the composite curve, so if I take the compositor; that means, this is the hot stream this is the cold stream and when hot stream is giving heat to the cold stream the temperature difference is this much for this place. This temperature difference is this much for his place this temperature difference is this much; that means, the driving force which is available is shown by the distance between this and this if I go to the diagram. And place this available temperature difference, then this plot I get the distance between this and this is shown is shows the driving force, which is available, so here I see the distance between this; and this is equal to the distance between this and this is the composite curve.

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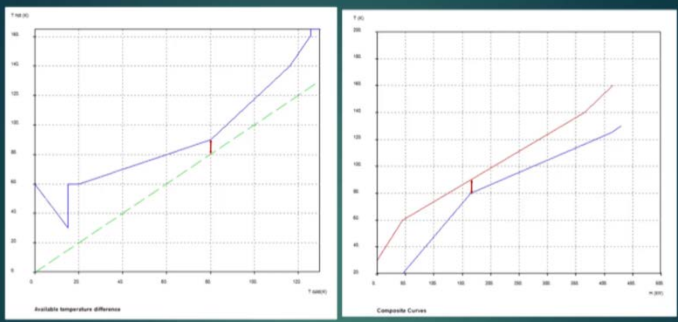

Stream Name	Supply Temperature	Target Temperature	CP(kW/°C)	H, kw/m^2 K
H-1	160	60	2.5	2
H-2	140	30	1.5	2
C-1	20	125	2	2
C-2	80	130	3.5	2

And this is the driving force plot the distance between this and this is distance between this and this now when we place heat exchanger, if the heat exchanger utilizes this driving force nicely or properly the obviously. The area of the heat exchanger will be less, and if it is not able to utilize this driving force properly then area will be more. So, we have to place the temperature profiles of the heat exchanges. On this driving force plot and then only we can know about this, if we take a second problem see this and solve it with hint. We get a driving force plot like this here; the driving force is less this is shown here and basically the driving force plot is between the temperature of the cold stream versus the temperature of the hot stream and in this plot we are measuring the driving force from diagonal line upward.

Thank you.