Process Integration
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Module - 4
Targeting
Lecture - 8
Area Targeting- 2nd Part

Welcome to the lecture series on Process Integration. This is module-four, lecture-eight; area targeting-part two. In this area targeting, we will see that how to do the area targeting of heat exchanger networks, when the heat transfer coefficient of all streams are equal.

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Heat exchanger area target is an important target has by knowing the area of a heat exchanger network, we can estimate the capital cost of the heat exchanger network very accurately. And this helps us to optimize the network or to select a optimum network out of many alternative combinations of heat exchanger networks. The principles of minimum area of a heat exchanger network is detailed in next slide.

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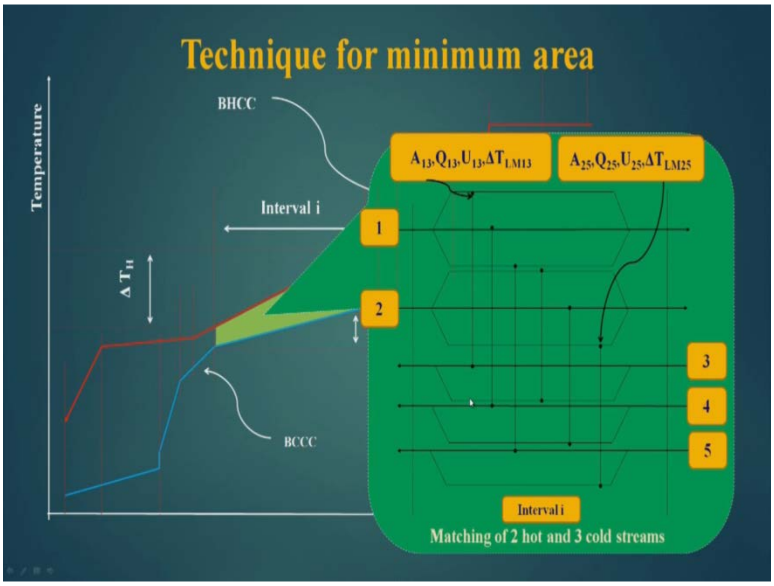

Now, to calculate the area of a heat exchanger network, which includes the area of heat exchangers, which take part in process-to-process heat transfer as well as the area of the heaters and area of the coolers. For this purpose, a BHCC and BCCC has to be plotted that means balanced hot composite curve and balanced cold composite curve has to be plotted. The figure shows such curves. Now in this figure, if it is broken into several components that means, several intervals, then we can have a interval like this which is called interval i. If we see this interval, the hot stream goes from here to here that means, the temperature drop takes place in this direction, and the cold streams temperature raises in this direction.

If we see these two lines then it resembles with the temperature profile of a counter current heat exchanger, and to calculate the area of a counter current heat exchanger we should know the value of Q that is capacity of the heat exchanger, which can be given by the distance from here to here. Because this is the delta H axis and this is the temperature axis, so Q is known. The log mean temperature difference can be calculated from temperatures of this two end, that is this is hot in, this is cold out, this is hot out and cold in. Using this four temperatures, the log mean temperature difference can be found out. If the overall heat transfer coefficient or the individual heat transfer coefficient of this streams, which are present here and the streams which are present here are known, then we can easily compute the area of this segment that is interval i of the balanced hot and cold composite curve.

So, the balanced hot and cold composite curves gives me a way to find out or a method to find out the area of the heat exchanger network. We can divide the balance sheet composite curves and different intervals, we can find out the area of each interval and we can add them up to find out the total area of heat exchanger network. Now in this, we consider that the vertical heat transfer takes place; that means, vertically the heat moves to the cold streams. And this is possible if I split the hot streams of interval i, and I split of the cold stream of interval i. In such a way that the number of splitted hot streams the number of splitted cold streams becomes equal, so that every splitted stream gets an opportunity to transfer heat to the corresponding splitted cold streams. Now how this will be done.

Now, let us concentrate on this part of the splitting process, where we are matching two hot streams with three cold streams; that means, in interval i, and the composite hot stream - there are two hot streams. And here in the composite cold streams, there are three cold streams presented. Now as there are number of cold streams is equal to 3 then each hot stream will be splitted into three parts. So, this is stream number one splitted into this part – 1, 2, and 3. Number two hot stream is also splitted into three parts 1, 2 and 3. And the cold streams are splitted into two parts which is the number of hot streams; as number of hot stream is two each cold stream will be splitted into two parts. The third number of cold stream is splitted into 1 and 2; fourth number 1 and 2; fifth number 1 and 2.

If we split in this way, the number of hot streams that is splitted hot streams is six now, and the number of splitted cold stream is six again. So, this splitted part of the hot stream one can exchanged to this splitted part of the hot stream three. And in this exchange the area is 1 3, the Q transacted is 1 3; U is 1 3, and delta T Lm is 1 3. Similarly, when the third splitted part of the hot stream 2 is exchanging heat with the splitted part of the cold stream 5, the area is 2 5; two stands for this and five stands for this. Q is 2 5; u 2 5, and delta T Lm 2 5. When we break these streams in such a way one can guaranty that vertical heat transfer will take place within the enthalpy interval. This type of splitting arrangement is assumed for all enthalpy intervals.

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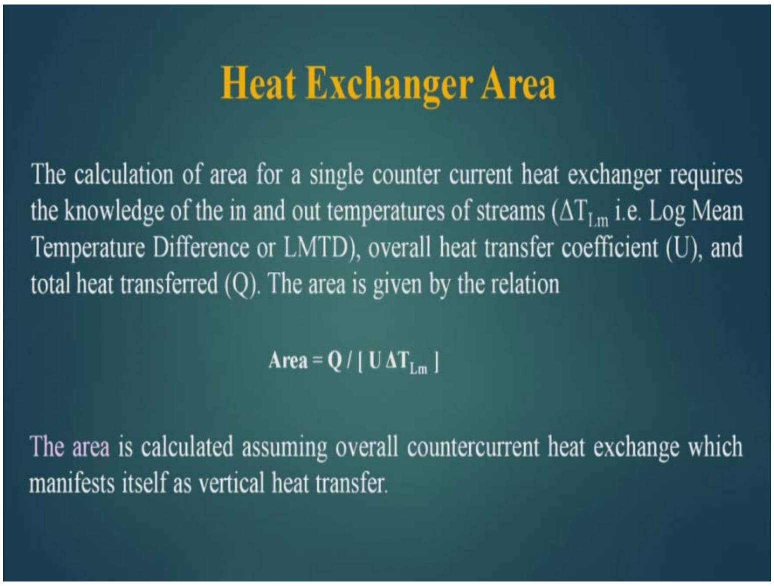

When the computation of area for a single countercurrent heat exchanger requires the knowledge of in and out temperatures of this streams to compute log mean temperature difference, overall heat transfer coefficient U, and the total heat transfer Q. And if it is so, then we give the area with this equation. Area is equal to Q divided by in brackets U delta T Lm log mean temperature difference. The area is computed assuming overall countercurrent heat exchange which manifests itself as vertical heat transfer.

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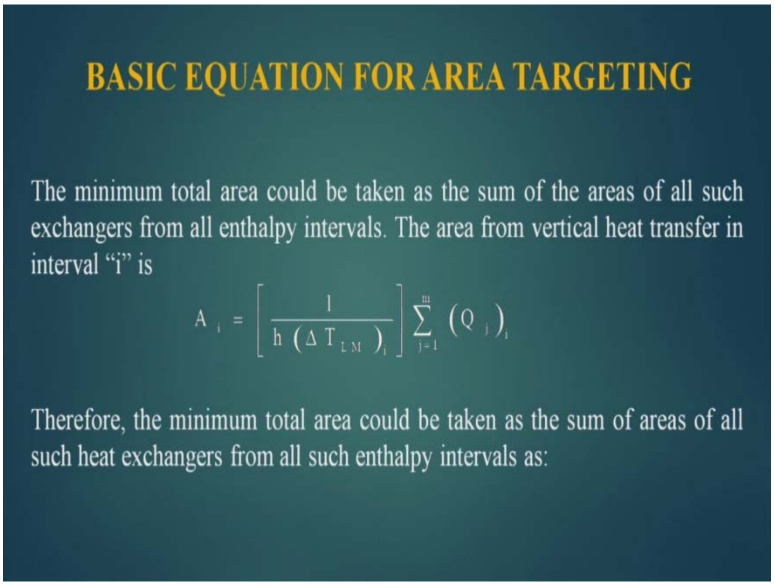

Now then the minimum total area could be taken as the sum of the areas of all such exchangers from all enthalpy intervals. The meaning that when we break the balanced hot and cold composite curves into a number of enthalpy intervals. The area from vertical heat transfer in enthalpy interval i is given as A i 1 by h delta T Lm i then summation of j equal to 1 to m Q j for i. This means that as heat transfer coefficient of the hot as well as cold streams in i enthalpy interval is considered to be fixed or constant, the h comes out. And in a enthalpy interval i, if the log mean temperature difference is delta T Lm i then it is also fixed for that intervals. So, h and delta T Lm comes out and what is changing is Q j. And Q j is the amount of heat received are given by a cold stream or hot stream in the interval i. And in this interval, there can be m number of streams, which includes cold streams and hot streams and the utilities. Therefore, the minimum total area could be taken as the sum of the areas of all such heat exchangers from all such enthalpy intervals.

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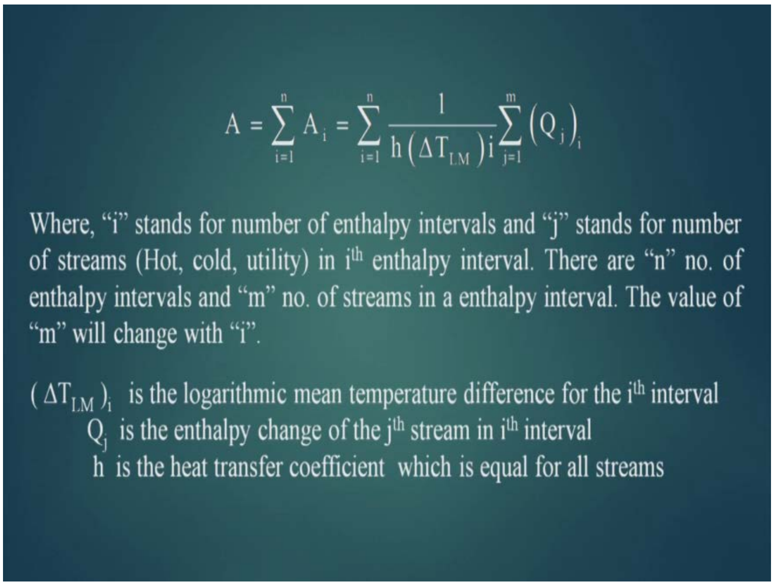

And we can find out the total area A is equal to summation of areas of intervals enthalpy intervals i, i is equal to one to n; that means, there are n number of enthalpy intervals considered in balanced hot and cold composite curves. So, our equation is given by this. Where delta T Lm i is the logarithmic mean temperature difference for the i eth interval; Q j is the enthalpy change of the j eth stream in i eth interval which considers both cold as well as hot streams and utility streams; h is the heat transfer coefficient which is equal for all streams in this case. n stands for number of enthalpy intervals, and m is the number of streams in a enthalpy interval, and the value of m will change with i. And this is so because at different temperature intervals, there will be different number of hot and cold streams.

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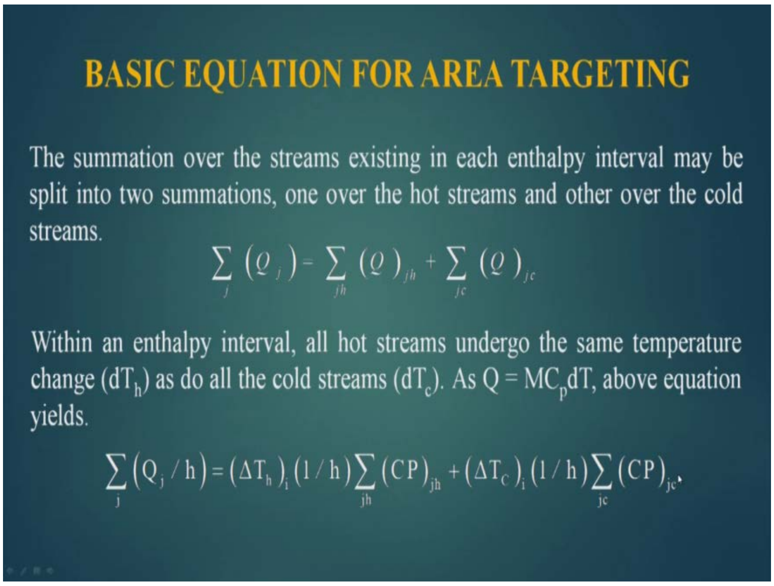

The summation over the streams existing in each enthalpy interval may be splitted into two summations. The Q j here represents cold streams, hot streams, and utility streams - cold utility and hot utility. This summation can be splitted into two summations, one for the hot streams and other for the cold streams. When I say hot streams, it includes the utilities; and when I say cold stream, it includes the cold utility. Within an enthalpy interval, all the hot streams undergo the same temperature difference; that means, in a i interval - enthalpy interval, all the hot streams present in the BHCC will raise to the same temperature difference, which is dT h. Similarly, all cold streams will be heated up by dT c.

And if we assume Q is equal to M C p dT then the Q for hot stream will be M C p d h T h, and for cold it will be M C p dT c. If I do so then Q can be substituted by M C p dT. And if we do this, this equation converts into this equation. What more has been done that Q has been divided by h; where h is a constant value in this case. So, this can be written as delta T h 1 by h summation C p h; where this C p is the specific heat mass flow rate multiplication for hot streams, and here this is for cold streams. So, this equation converts into this equation.

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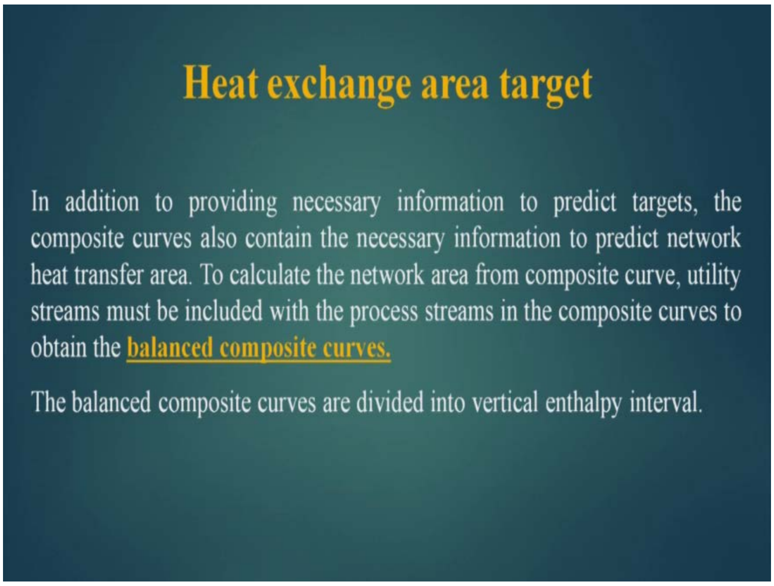

In addition to providing necessary information to predict targets, the composite curves also contain the necessary information to predict network heat transfer area. To calculate the network area from composite curve, utility stream must be included with the process streams in the composite curves to obtained balanced composite curves. Because the in area targeting, the area of heaters as well as coolers are also included and this only we can find out if we take a balanced composite curve. The balanced composite curves are divided into vertical enthalpy intervals as discussed.

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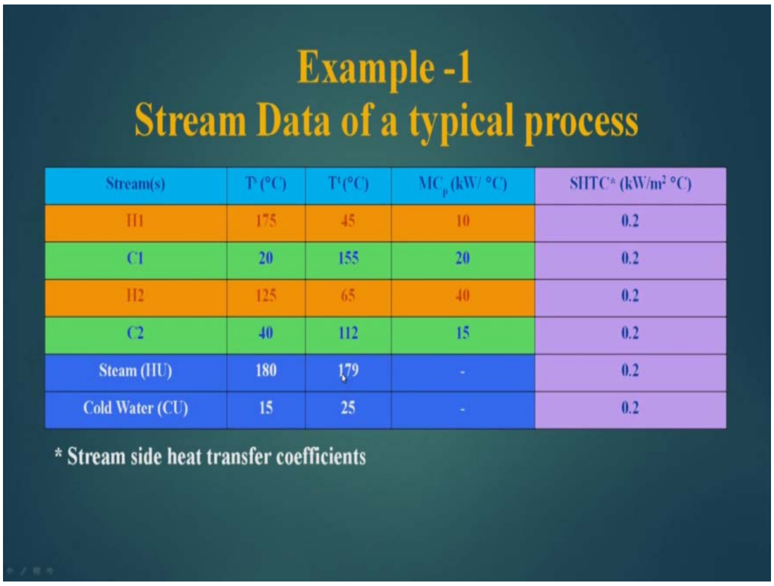

Stream(s)	T^s (°C)	T^t (°C)	MC_p (kW/ °C)	SHTC* (kW/m² °C)
H1	175	45	10	0.2
C1	20	155	20	0.2
H2	125	65	40	0.2
C2	40	112	15	0.2
Steam (HU)	180	179	-	0.2
Cold Water (CU)	15	25	-	0.2

Now, let us take as an example. So for this, we take this example of two hot streams, two cold streams, one hot utility and one cold utility. The supply and target temperature of hot streams are given; supply temperature of H 1 is 175, and target temperature is 45. M C p that is capital C p is 10. And heat transfer coefficient is 2. Now when we are going for area targeting, this column is added extra; that means, heat transfer coefficient of all the streams must be available with this stream data table if we are performing area targeting. Now C 1 - this is cold stream 1, the supply temperature is 20, targeted temperature is 155; and the capital C p value, which is 20 here; and the heat transfer coefficient is 0.2. Here we will observe that the heat transfer coefficient of all the streams are equal and the algorithm which we are using is for heat transfer coefficient of all streams equal and that is why we find this.

The H 2 is, supply temperature 125, the target temperature 65, and the capital C p value is 40 like this. This stream at 100 degree centigrade and the target temperature is 179 degree centigrade, one degree less than this I have already explained why we take this. Because the C p value of a steam condensing is infinite to safeguard this, we see that the value of stream is changing by a degree or so. And in practical situation also, it will change to some extent, so that the C p value becomes non-infinite value. The cold-water inlet temperature is 15 - supply temperature and it rises to 25 degree centigrade, and the steam side heat transfer coefficients are constant or 0.2, and the delta T minimum taking is 20 degree centigrade.

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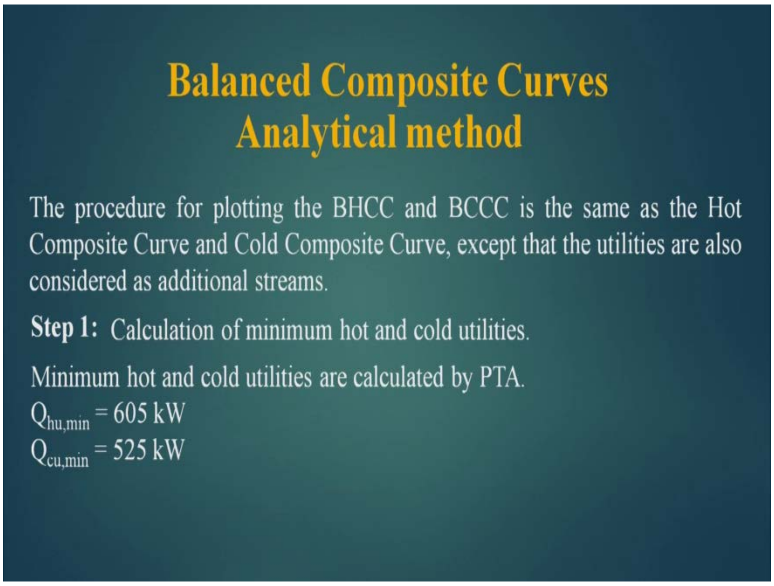

Now, our job is to find out the balanced composite curve. The procedure for a plotting balanced hot composite curve and cold composite curve is the same as hot composite curve and cold composite curve, except that the utilities are also considered as additional streams. Step one: calculation of minimum hot and cold utilities. Once the stream table data is available to us, so we can go for a PTA, and then we can find out what is the minimum hot utility requirement this is in this case 605 kilowatt and minimum cold utility requirement is 525 kilowatt.

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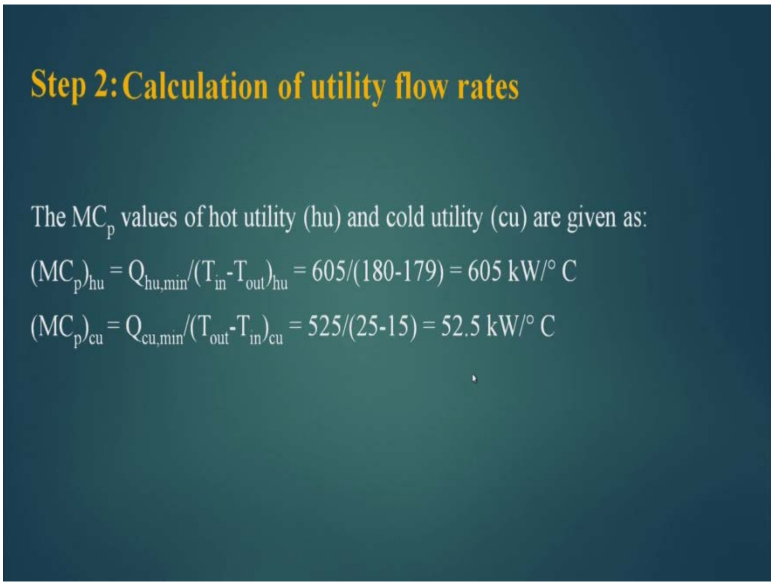

Now, the next step is that mass the values of utilities of the amount of the utilities are known. We will try to calculate the capital C p or M C p value of hot utility as well as M c p value of cold utility. So, here M C p value of hot utility is 605 divided by 180 minus 179, it comes out to be 605 kilowatt per degree centigrade. Similarly, the capital C p or M C p value of the cold utility is 52.5 kilowatt per degree centigrade.

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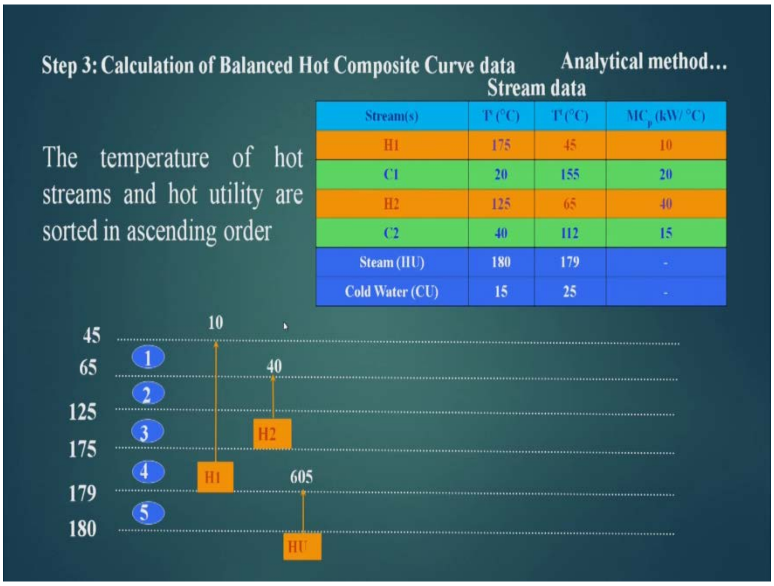

Now what we do to find out the required data to plot a balanced hot composite curve, we will only considered the hot streams and hot utility streams for this purpose from the stream data. And we will put the temperature levels in rising order. So, 45 then comes 65 and then comes 125, 175, 179, 180, so there are increasing order. We have put this data in increasing order. So, these are the temperature level data, and these are the intervals - temperature intervals. Now we can plot the streams. So, H 1 stream moves from 175 to 45, the H it has got a C p value of 10, H 2 stream is 125 to this is from this to this, this is from this to this, and stream is from 180 to 179.

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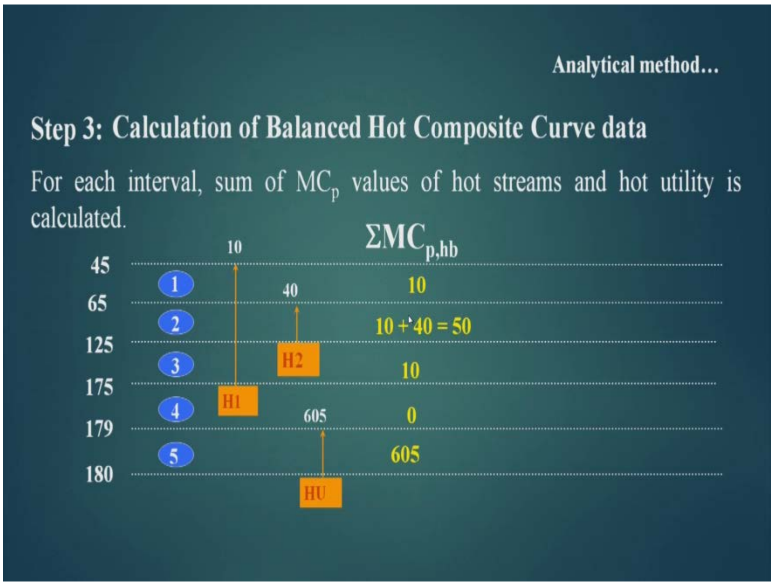

Now, we will compute the M C p values for hot streams at different temperature intervals. This is 10, because in these temperature intervals 65 to 45, there is only one hot stream present, and its M C p value is 10. But in this temperature interval 125 to 65, two hot streams are available whose combined M C p value is 10 plus 40 is equal to 50 and so on so forth. We can fill up this column.

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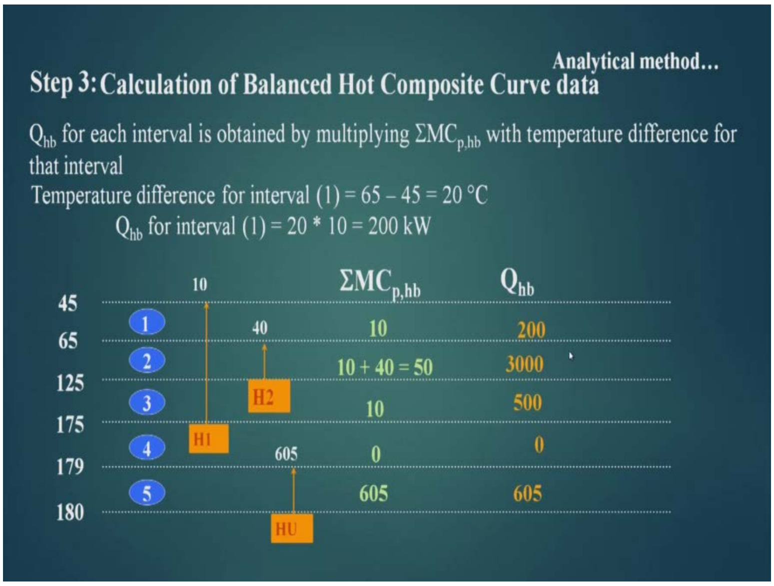

Now, we can calculate Q hb - that means what is the heat available in this temperature intervals, because we are integrating based on temperature intervals.

So, heat available is the delta T of this into the M c p values. So, here this is 10 and the delta T value is 65 minus 45 – 20, so 20 into 10 is 200, and we can fill it up like this.

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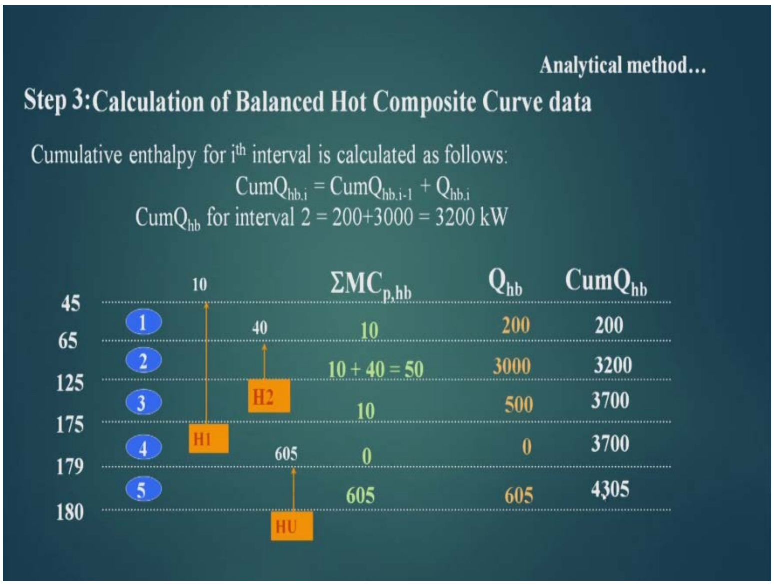

Now, cumulative heat available in these intervals is necessary to plot the hot balanced hot composite curve. So, we find out cumulative and this is the value is 200. For this temperature level, it is 3000 for plus 200 that is 3200, so this is 3200. And for this, it will be this value plus this value plus this value and so on so forth.

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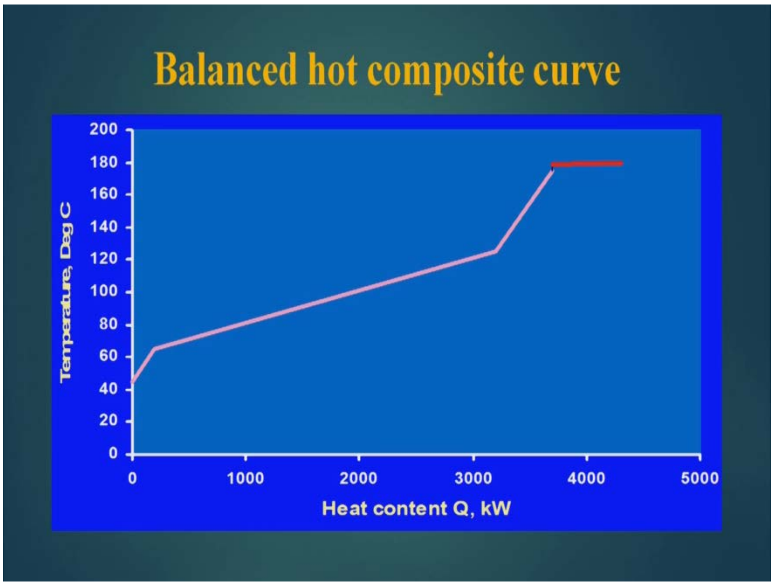

Now, based on that cumulative value and the temperature levels, we can plot the balanced hot composite curve. Now our balanced hot composite curve is ready. So, the next step is to find out data for plotting the balanced cold composite curve.

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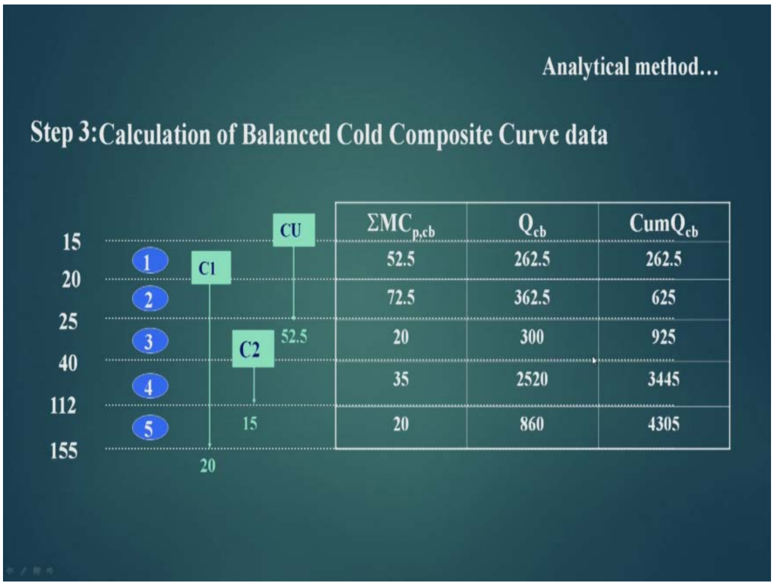

So, for the balanced cold composite curve, in the similar manner, we have computed the M C p of cold composite curve then Q cb then cumulative Q cb. Once these data is known to us, we can plot the balanced cold composite curve.

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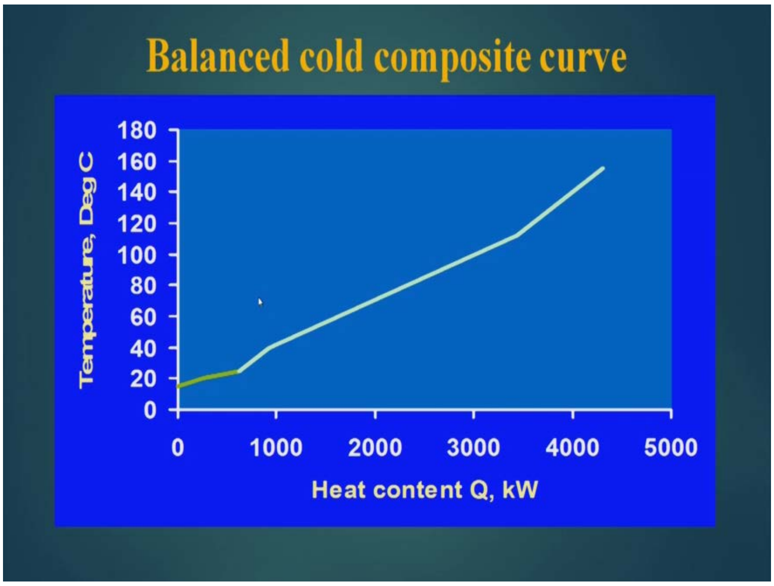

Then we have to put these two curves in one plot, so that the delta T minimum is 20 degrees centigrade.

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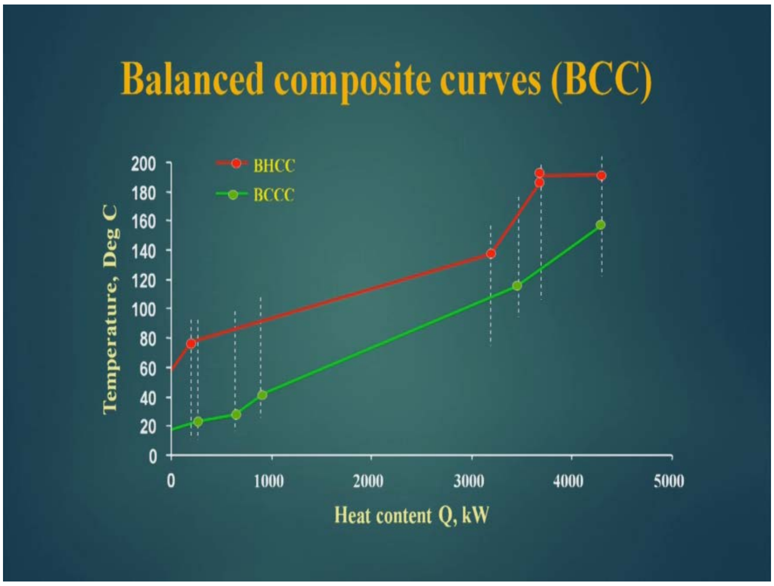

Now this point is you see that in the balanced hot composite curve or the balanced cold composite curve, where the line is changing slope that point is known. Because this is the point, where either the inlet temperature or the outlet temperature of the stream individual stream exists, so that is why these temperatures are known where the slope is changing. So, this temperature is known, but this corresponding this temperature is not known of the cold. Now cold slope change at this point. So, this temperature is known, but the corresponding temperature at the hot composite curve is not known. Similarly, we can plot this.

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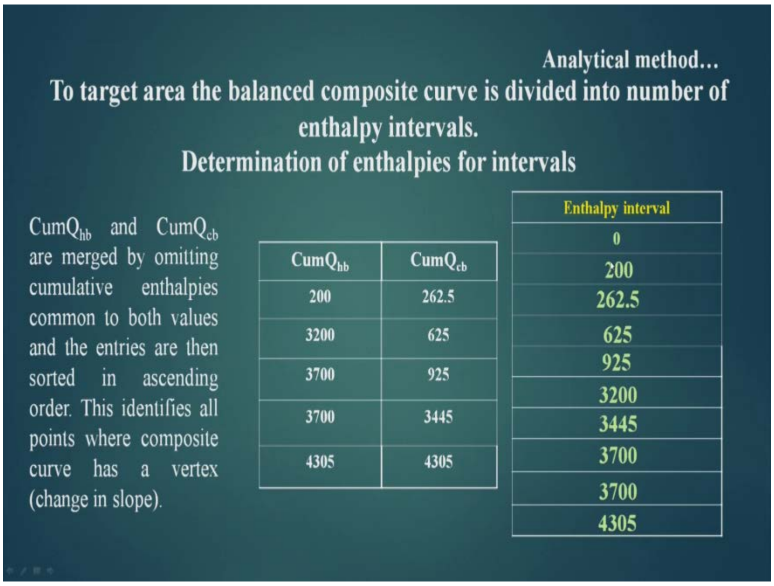

Now what we will do our next job is to find out the temperatures of the hot composite - balanced hot composite curve, and balanced cold composite curve where it is not known. For that, we will put up cumulative hot cumulative cold enthalpies, and we will merge them by omitting cumulative enthalpy is common to both values, and the entries are then stored in ascending order, this identifies all the points where composite curve has a vertex. Two and after that it is 262.5 then 625 then 925, so these are in ascending order.

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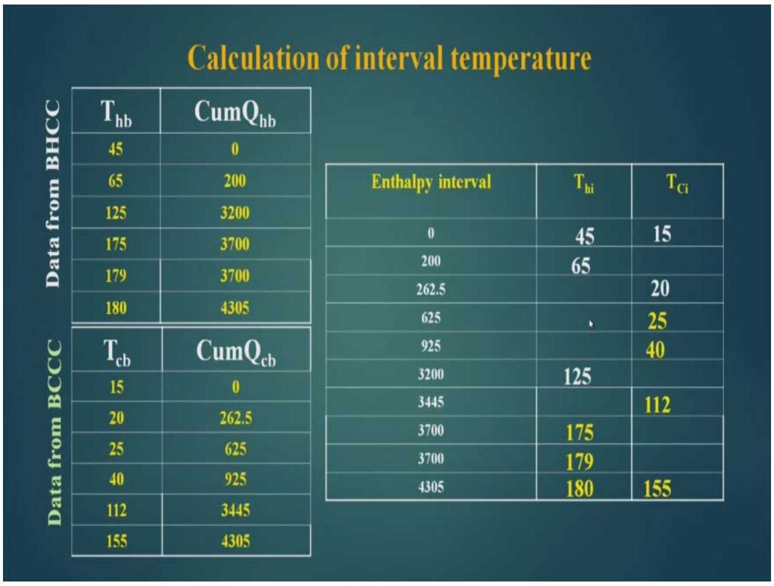

Now our aim is to find out the interval temperatures where it is not available. Now, 45 this available, this is hot inlet temperature. So, at 200, which is a cumulative value taking from hot balanced hot composite curve, the temperature is 65. Then it is 3200, so 3200 is this, here I have a temperature. Similarly, other temperatures are written. So, for hot composite curve, this temperature, this temperature, this temperature and this temperature is not known. Similarly, I can have for zero - this is 15, we have written the 15. The next comes 262.5; 262.5, we have a temperature for balanced cold composite curve; it goes there; similarly here.

So, the corresponding temperatures of the cold composite curve, corresponding to 125 is not known, corresponding to 175 is not known, 179 is not known. Similarly corresponding to 65 this temperature is not known; for corresponding to 20, this temperature is not known, this temperature is not known, this temperature is not known. So, main job is now to find out this temperature, the missing temperatures. Why we are doing so, because for an enthalpy interval, all the four temperature that is two hot temperatures and two cold temperatures should be known. And if it is not known, we cannot find out the delta T Lm that is log mean temperature difference. And hence all the temperatures, missing temperatures should be first found out.

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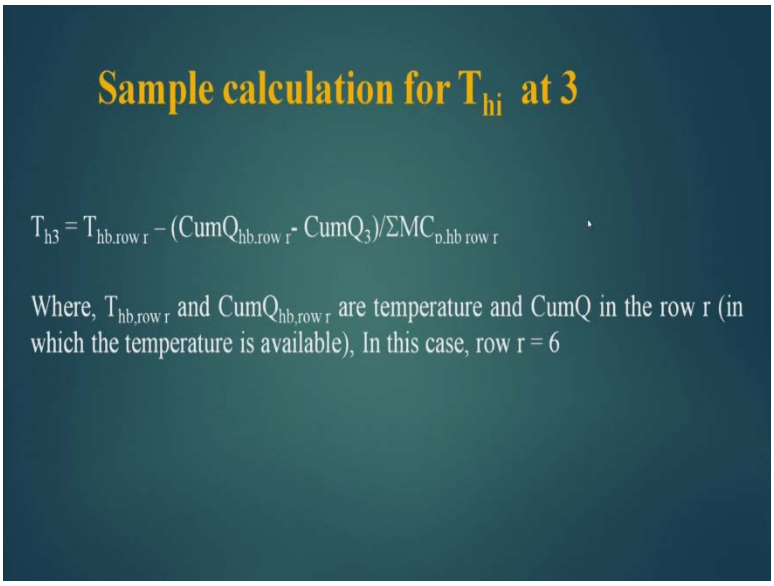

So, these are the equations through which we do this is basically a linear interpolation equation, and we have discuss this in area targeting. So, I am quickly skip this.

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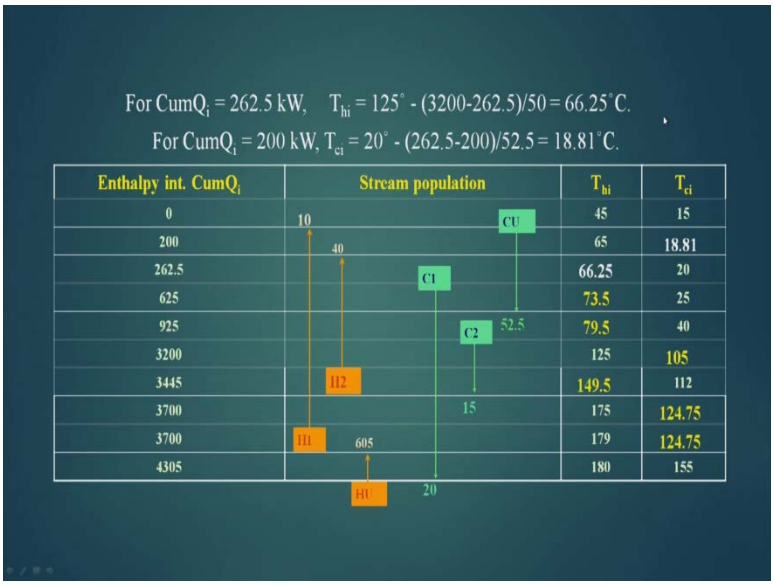

We are computing the unknown temperatures. This shows an example how to compute the temperature. So, this unknown temperature was computed using this equation. Similarly, we will fill it up T ci is equal to this known temperature minus this enthalpy values, and then we have also use the summation of C p values from this area and we find out this is 18.81 . So, now, we are able to fill up all the temperatures required to for the computation of L M T D.

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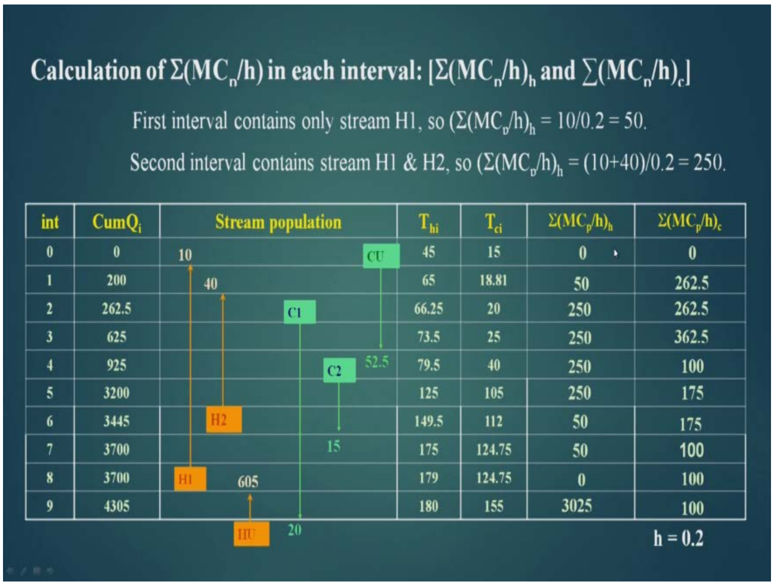

int	CumQ$_i$	Stream population	T_{hi}	T_{ci}	Σ(MC$_p$/h)$_h$	Σ(MC$_p$/h)$_c$
0	0	10 CU	45	15	0	0
1	200	40	65	18.81	50	262.5
2	262.5	C1	66.25	20	250	262.5
3	625		73.5	25	250	362.5
4	925	C2 52.5	79.5	40	250	100
5	3200		125	105	250	175
6	3445	H2	149.5	112	50	175
7	3700	15	175	124.75	50	100
8	3700	H1 605	179	124.75	0	100
9	4305		180	155	3025	100

Now our job is to find out the M C p by h values for the hot as well as cold that is very simple. M C p by h will be for this the M C p is zero; for this temperature interval, the M C p is 10, and our h value is 0.2. So, this 10 divided by 0.2 is 50, so 50 comes here. Similarly, for this the M C p value is 10 plus 10, then divided by 0.2, so it becomes 250. In the similar manner, we can also find out the M C p by h values for cold, which are given in this column. Why we are doing this, basically our aim is to compute the Q value and Q is M C p dT.

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Calculation of $\Sigma(Q/h)$ in each interval

For first interval

$$\sum (Q/h) = (65^\circ - 45^\circ)50 + (18.81^\circ - 15^\circ)262.5 = 2000$$

For second interval

$$\sum (Q/h) = (66.25^\circ - 65^\circ)250 + (20^\circ - 18.81^\circ)262.5 = 625.$$

int	T_{hi}	T_{ci}	$\Sigma(MC_p/h)_h$	$\Sigma(MC_p/h)_c$	$\Sigma(Q/h)$
0	45	15	0	0	
1	65	18.81	50	262.5	2000
2	66.25	20	250	262.5	625
3	73.5	25	250	362.5	
4	79.5	40	250	100	
5	125	105	250	175	
6	149.5	112	50	175	
7	175	124.75	50	100	
8	179	124.75	0	100	
9	180	155	3025	100	

So, it is Q by h, it will compute, because we have computed M C p by h. So, Q by h will be M C p by h into delta T. So, Q by h is equal to this is delta T, this is the M C p value, this is for hot, and this is the delta T value for the cold and the M C p value of the cold. So, this Q h is the summation of Q h hot and Q h cold. And Q h hot is given by this delta T into 50, and this delta T which we observe here is delta T h and this is delta T c; that means, drop in the temperature of the composite hot stream of a certain interval, that is the interval one. And raising the temperature of the cold stream the temperature interval one.

So, we can calculate this value and we can put it here, 2000. Similarly, for the second interval, this is the value. So, we are using this two and this two values and this two M C p by h values. So, this minus this into 250, this value and this minus this into 262.5 this value and we take summation of it comes about 625. So, it goes to 625, so we fill it up.

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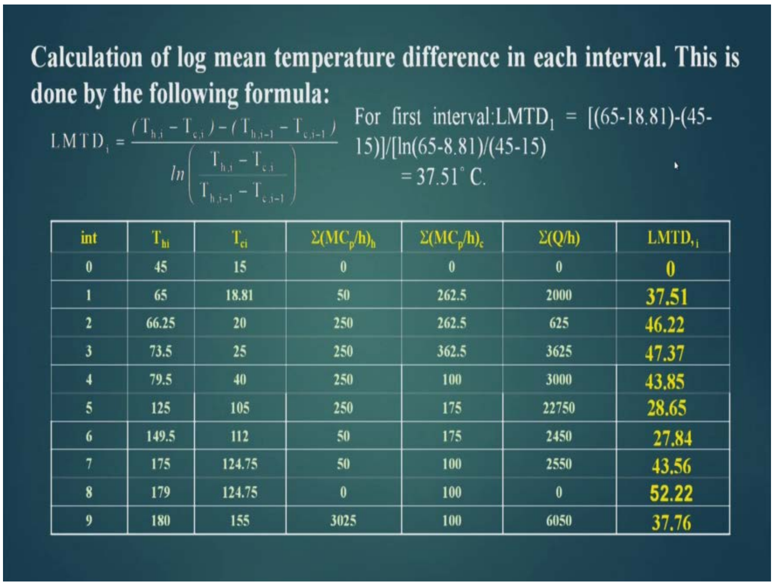

Now the next job is to find out LMTD, now LMTD. To find out the LMTD of a particular interval, four temperatures should be known two hot temperatures and two cold temperature. For the interval one these are two hot temperatures and these are the two cold temperatures. So, we can find out the LMTD for all the intervals, because all the temperatures are known. So, this is the equation for LMTD. For interval LMTD 1, this is 65 minus 18.81 minus 45 minus 15 divided by log this it becomes 37.5, so 37.51 one goes here. Similarly, we can compute L M T ds for this. So, now we have Q values, we have LMTD values, and hence we can find out the area because Q is known h is known LMTD is known. So, the area can be find out.

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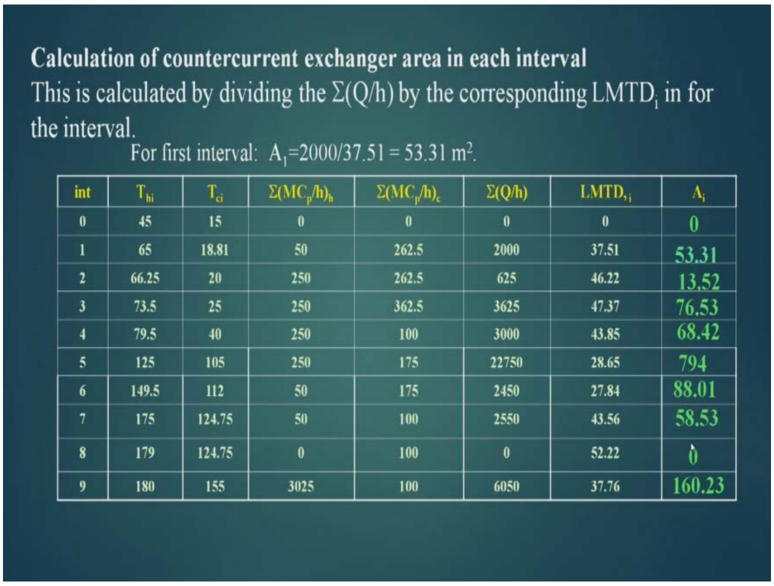

int	T_{hi}	T_{ci}	$\Sigma(MC_p/h)_h$	$\Sigma(MC_p/h)_c$	$\Sigma(Q/h)$	$LMTD_{,i}$	A_i
0	45	15	0	0	0	0	0
1	65	18.81	50	262.5	2000	37.51	53.31
2	66.25	20	250	262.5	625	46.22	13.52
3	73.5	25	250	362.5	3625	47.37	76.53
4	79.5	40	250	100	3000	43.85	68.42
5	125	105	250	175	22750	28.65	794
6	149.5	112	50	175	2450	27.84	88.01
7	175	124.75	50	100	2550	43.56	58.53
8	179	124.75	0	100	0	52.22	0
9	180	155	3025	100	6050	37.76	160.23

So, area of each interval would be computed now. So, the first interval area is 2000 divided by 37.51, this is 2000 is Q by h and this is LMTD. So, we divide this value with this value, we get the area of the interval, so it is 53.32 and goes there. Similarly, we can find out the area of all the enthalpy intervals, all the nine enthalpy intervals. So, we fill it up. Here, we get the zero area, because this corresponds to a artificial point, where temperature raises immediately and the enthalpy content of that link is zero. So, the total area is 1312.57 meter square. This area is the minimum area of the heat exchanger network. And we have used the bath algorithms for this purpose.

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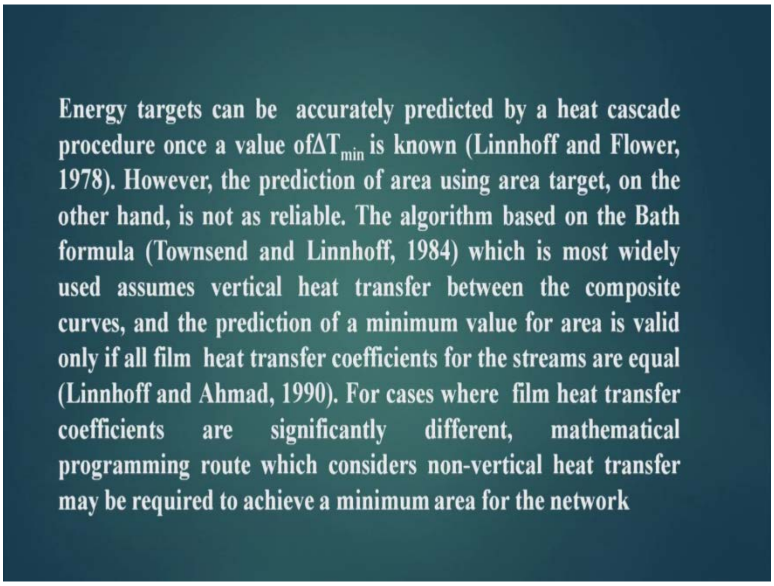

Now we need to have a discussion on this. Energy targets can be accurately predicted by a heat cascade procedure once the value of delta T minimum is known. However, the prediction of area using area target, on the other hand, is not as reliable. The algorithm based on the Bath formula Townsend and Linnhoff in 1984 which is most widely used assumed vertical heat transfer between the composite curves and the prediction of a minimum value for area is valid only if all heat film heat transfer coefficients for the streams are equal. This has been shown by the Linnhoff and Ahmad.

Now, if the heat transfers coefficients are different or different in comparison to each other by 10 percent or so, the area which we will be computing will not be a minimum area. For cases where film heat transfer coefficients are significantly different, it will not give minimum area using the bath algorithm in area targeting. Then the mathematical programming route, which considers non-vertical heat transfer may be required to achieve a minimum area of the network. So, this should be kept in mind that for the cases where film heat transfer coefficients are significantly different that is more than 10 percent different, then the area which will be predicted by this algorithm bath algorithm will not be minimum in nature. Then we have to use mathematical programming; but in the mathematical programming, it considers non-vertical heat transfer. Thank you.