Process Integration
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Module - 4
Targeting
Lecture - 7
Area Targeting - 1st Part

Welcome to the lecture series on process integration. This is module 4, lecture number 7, the topic of lecture is area targeting. In this lecture we will see that how to find out, the area targeting of a HEN, and then when the hot and cold streams of the HEN have unequal stream heat transfer coefficient.

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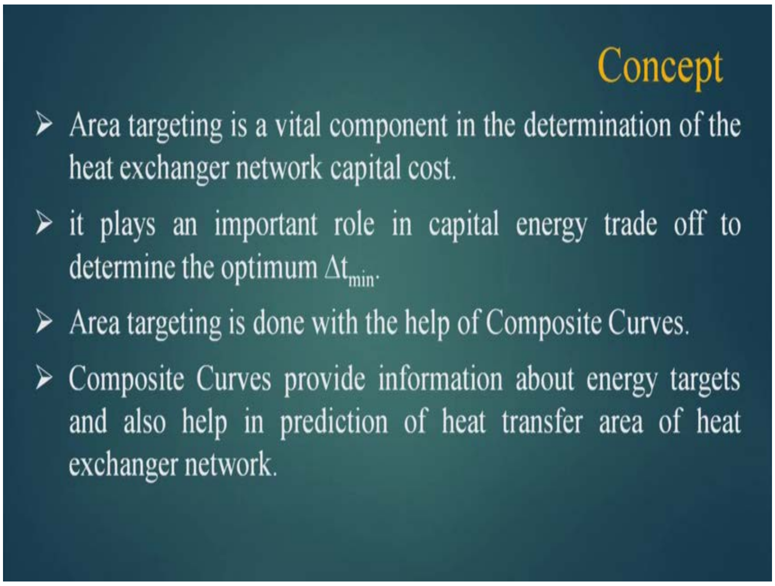

Area targeting is a vital component, in the determination of the heat exchanger network capital cost. It plays an important role in capital energy trade off, to determine the optimum delta t also. Basically, when we design a HEN using the pinch analysis for a given problem then, many heat exchanger networks can be created based on the value of delta t minimum. Then, an optimum delta t minimum is selected which keeps the tack of the HEN as minimum.

To do so one should calculate the capital cost of the HEN for each delta t minimum, as well as the operating cost of the HEN for each delta t minimum. The operating cost can be found out, from the energy target and the capital cost can be found out from the area target. Because, once we know the area of the heat exchanger network, capital cost can easily be found out. Area targeting is done with the help of composite curves, which we have already seen how to generate a hot composite curve and how to generate a cold composite curve. Composite curves provide information, about energy targets and also help in the prediction of heat transfer area, of heat exchanger network.

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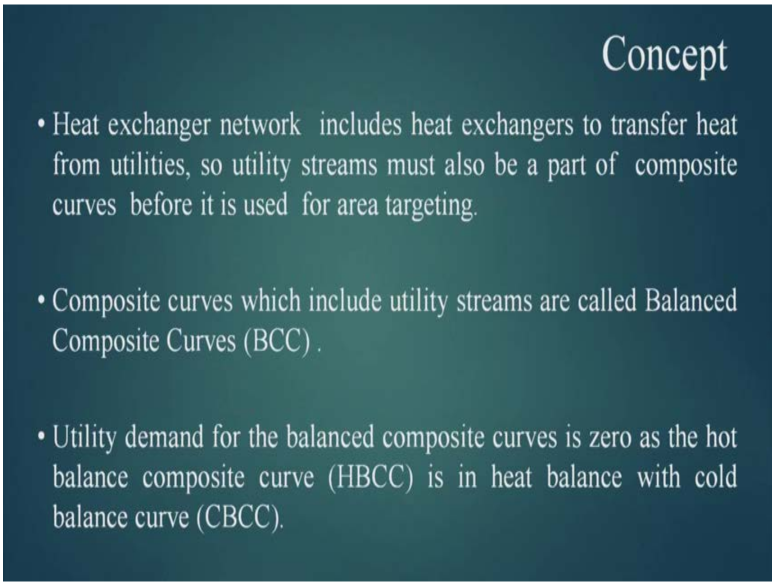

Now in a heat exchanger network, we find different heat exchangers some of which use to transfer, heat from process hot to process cold. Others are used to transfer heat from utilities and hence both types of heat exchangers should be included in the heat exchanger network. And this can be done, when utility streams forms a part of the composite curve, before it is used for area target. Composite curves which include utility streams are called balanced composite curves, utility demand for the balanced composite curve is 0, as the hot balanced composite curve which is called HBCC, is in heat balance with cold balance curve, which is called CBCC.

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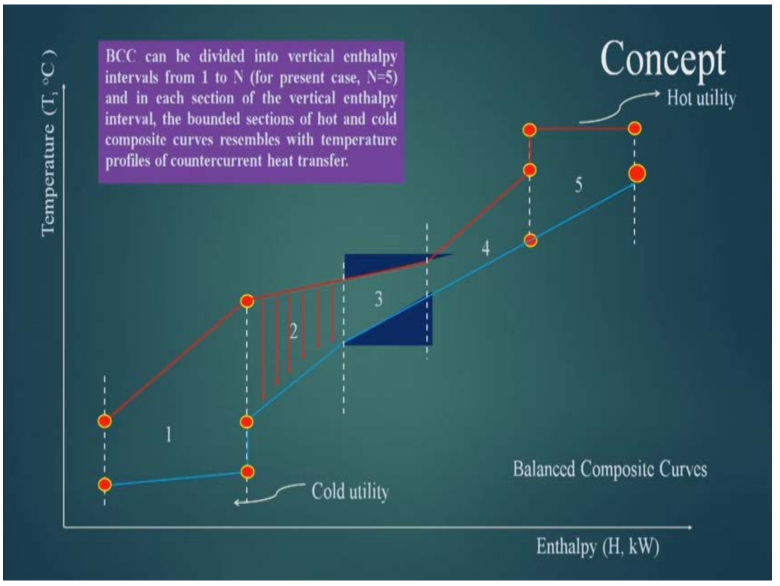

Now the figure shows a composite or a balanced composite curve, the upper one shows a balanced hot composite curve where, this part of the hot composite curve shows the hot utility. And this shows a balanced cold composite curve, where this part of the curve shows the cold utility. The balanced composite curve which is drawn between axes temperature and delta h, which is enthalpy, can be divided into vertical enthalpy intervals from 1 to n.

In the present case n is 5, now the first one is this, which is number 1 vertical enthalpy interval, second is this which contains hot composite curve up to this. And cold composite curve up to this, then third one is this and so on, so forth. The bounded section of hot and cold composite curves, resemble with temperature profiles of a counter current heat transfer. If we see the part one of the vertical enthalpy interval, that is number 1 vertical enthalpy interval, this is the hot composite, which moves from here to here. This is a cold composite whose temperature, this is the inlet temperature, this is the outlet temperature, this resembles the temperature profile of a counter current heat exchanger.

If it is so and we know these two temperatures and we also know the overall heat transfer coefficient of this. And you can know the delta h part, which is from here to here. So delta h equal to q is known these four temperatures will give LMTD, log mean temperature difference. So, q is known, log mean temperature difference is known and if u is known then, area for this interval number 1 can be computed. Similarly, we can compute the area for interval number 2, interval number 3, interval number 4 and interval number 5. If we add these areas, then we find the overall area of the heat exchanger network.

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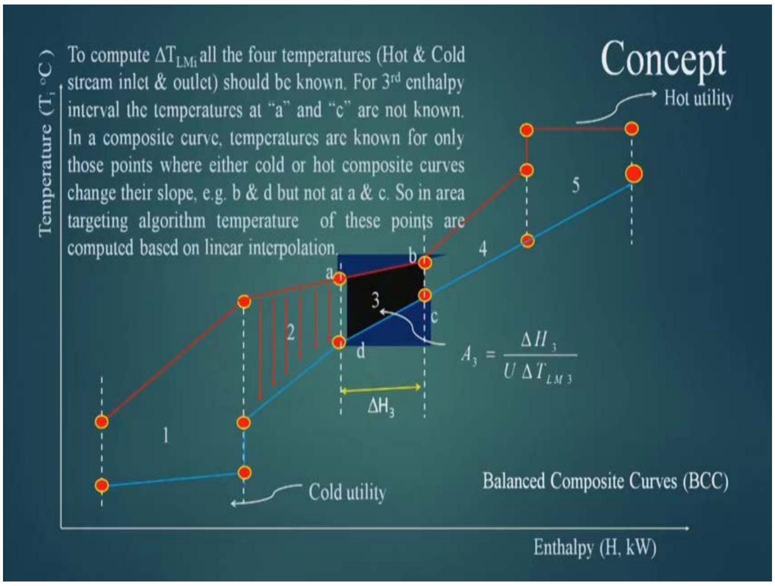

Further, if you see here, then you find that, there are few points which are not available. Like, if you see this number 3, that is third enthalpy interval, the temperature at a and temperature at c is known, temperature at a and temperature at c are not known in the composite curve.

So, these temperatures has to be found out before we go for area targeting. Similarly, here we see that where there is a change in the slope, from here we see there is a slope there is a change in slope in this zone. So, this point is always known similarly, if you see the slope is changing at this point. So, this temperature is known to us, but the slope is not changing from this point to this point so the corresponding temperature to this temperature d, which is a here is not known.

Similarly, there is a change in slope at b point so b point temperature is known, but c point temperature is not known, as there is no slope is changing. Unless otherwise, we know the temperature at a, d, b and c, we cannot find out the LMTD for this zone. And unless otherwise, we find out LMTD for this zone, we cannot find out the area of this zone within f, the u is available with us. So, the first step in the balanced composite curve will be to know the temperature of those points, in which temperature of either hot composite curve is not known or cold composite curve is not known.

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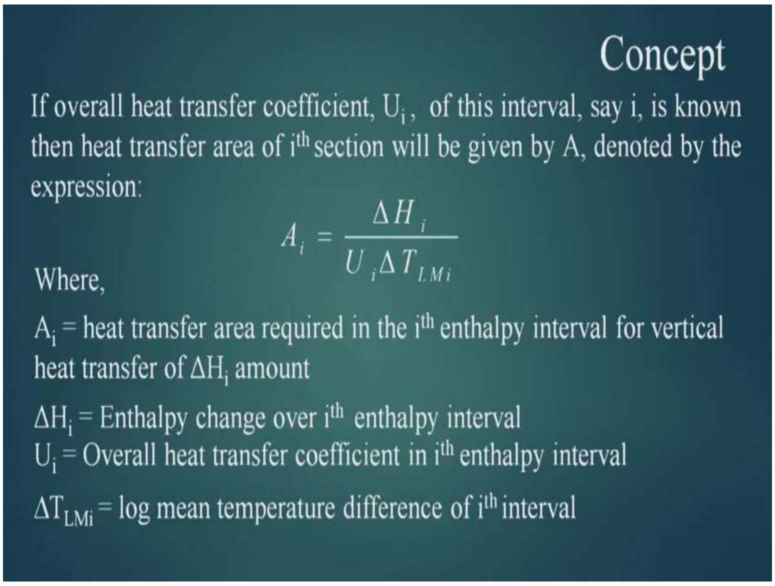

If the overall heat transfer coefficient of an interval i is Ui, then area Ai will be given by delta Hi, divided by Ui delta T LMi, that means the delta H of that interval i is, delta Hi, Ui is the overall heat transfer coefficient of ith enthalpy interval. Delta T LMi, is the log mean temperature difference of the ith interval and area Ai is the heat transfer area in the ith enthalpy interval, for vertical heat transfer of Hi amount. Here we are presuming that, vertical heat transfer is taking place in enthalpy intervals.

Now in such cases, generally delta Hi is known, Ui is known because U for, to calculate Ui we should know the individual heat transfer coefficient, of the stream. Those information's are known to us and in the problem this information is tabulated. However, delta T LMi has to computed and for this purpose, all the temperatures exit and the inlet temperature of the interval should be known. Now, there are two type of algorithms which are available for area targeting.

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The first algorithm is area targeting with equal heat transfer coefficient, which is comparatively simple. And the second algorithm is area targeting with unequal heat transfer coefficient, the topic of this lecture is area targeting with unequal heat transfer coefficient.

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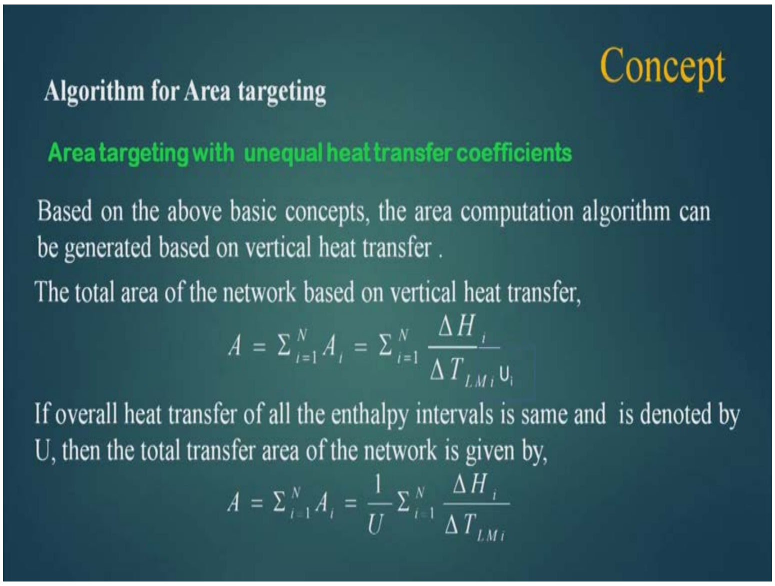

Let us see the algorithm of area targeting, when the streams have unequal heat transfer coefficient. Based on the concepts, which has been discussed earlier, the area computation algorithm can be generated, based on vertical heat transfer. The total area of the network, based on vertical heat transfer is a, which is equal to summation i equal to 1 to N. Where, there are n enthalpy intervals and Ai, is the area of the enthalpy interval i.

This is equal to summation i to N, delta Hi divided by delta T LMi into Ui. Now if the heat transfer coefficient is constant, then the Ui will take this f of u and it is constant. So, it can be taken out from the summation and the summation is equal to 1 by U summation i to N, delta Hi by delta T LMi.

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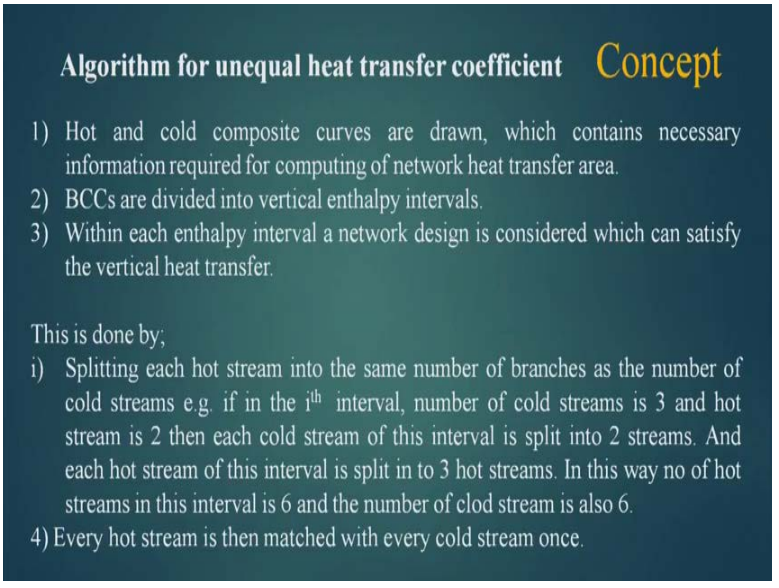

However, if the Ui is not constant then this formula cannot be used. Let us see some other part of the algorithm of unequal heat transfer coefficient. And these hot and cold composite curves are drawn, which contains necessary information required for computing network heat transfer area. And the composite curves are basically BCC curves, that is balanced composite curves, the balanced composite curves are divided into vertical enthalpy intervals. Within each enthalpy interval a network design is considered, which can satisfy the vertical heat transfer. And to satisfy this vertical heat transfer, some assumptions has to be taken or some manipulation needs to be carried out.

What is that manipulation, splitting each hot stream into the same number of branches, as the number of cold streams. That is, if in the ith interval number of cold streams is 3 and hot stream is 2, then each cold stream in this interval is splitted into 2 hot streams. And each hot stream of this interval is splitted into 3 hot streams, as the number of the cold streams. In this way number, number of hot stream in this interval becomes 6 and also the number of cold streams in this interval becomes 6. Once the number of hot streams is equal to number of cold streams in a interval, every hot stream is then matched with the every cold streams, by doing so we are able to do the vertical heat transfer.

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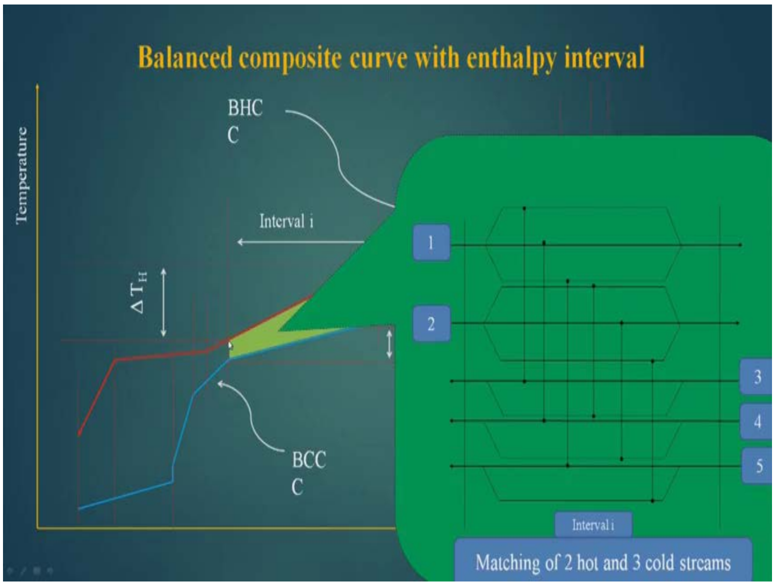

Now the figure shows, two balanced composite curves the first one is called BHCC balanced hot composite curve. And the lower one, which is in blue shows the balanced cold composite curve, BCCC. Here we see, that the hot utility has been added to this and here the cold utilities had been added to this.

In this BCC it is very clear, that the heat available with the process stream, hot process streams along with the hot utility is equal to the heat required by the cold utility and cold composite streams. Hence, it represents the complete heat exchanger network including heaters and coolers. So that means, if we find out the area using a balanced composite curve, which includes balanced hot composite curve and balanced cold composite curve, then whatever area we will find out, it will include the heaters and coolers and passes heat exchangers.

Now whatever we have seen in the algorithm, we will see now, here so it shows you a ith interval in the balanced composite curve, there are 2 hot streams available and 3 cold streams available. So, each hot stream is divided into 3 parts or splitted into 3 parts and each cold stream is splitted into 2 parts. And in this way, the heat exchange takes place that means, the first part of the hot stream 1, exchanges heat to the first part of the cold stream 3. So, this forms an exchanger network in the ith interval and facilitates the vertical heat transfer.

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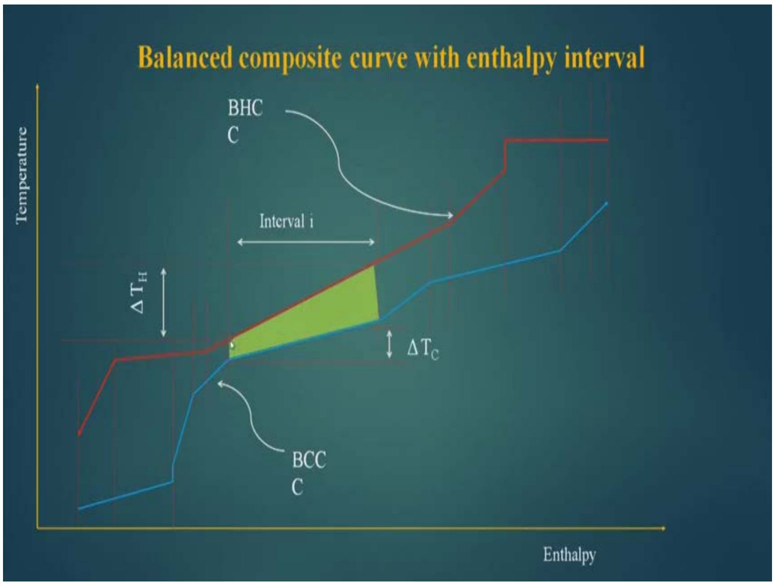

Here we see that, the hot composite hot stream rises from this temperature to this temperature, which is delta TH and the cold stream rises from this temperature to this temperature which is delta TC. Now, in this ith interval all the hot streams rise from this temperature to this temperature, that is delta TH, which remains constant for all the hot streams. And for the, all the cold streams of ith interval, the cold streams temperature rise from this point to this point which is delta TC.

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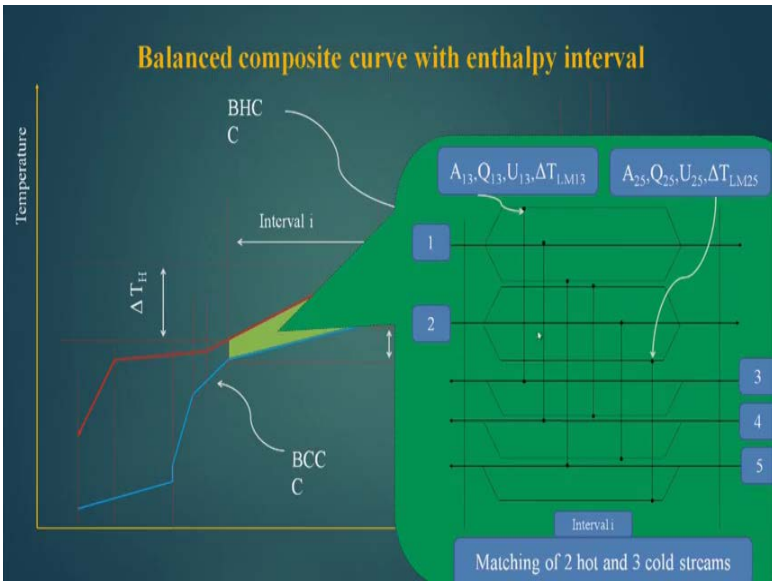

Now, if I number them that means for this heat exchanger, the area is 1 3 because 1 is exchanging heat with the cold stream 3, that is why the area is 1 3. And the Q exchanged in this heat exchanger is Q 1 3 and the overall heat transfer coefficient is U 1 3 and the delta t log mean temperature difference is delta T LM 1 3. Similarly, for this heat exchanger which is between stream number 2 and cold stream number 5, this is area, is 2 5. Heat transferred or the capacity of heat exchanger is Q 2 5, U overall heat transfer coefficient is U 2 5 and delta T LM is delta T LM 2 5.

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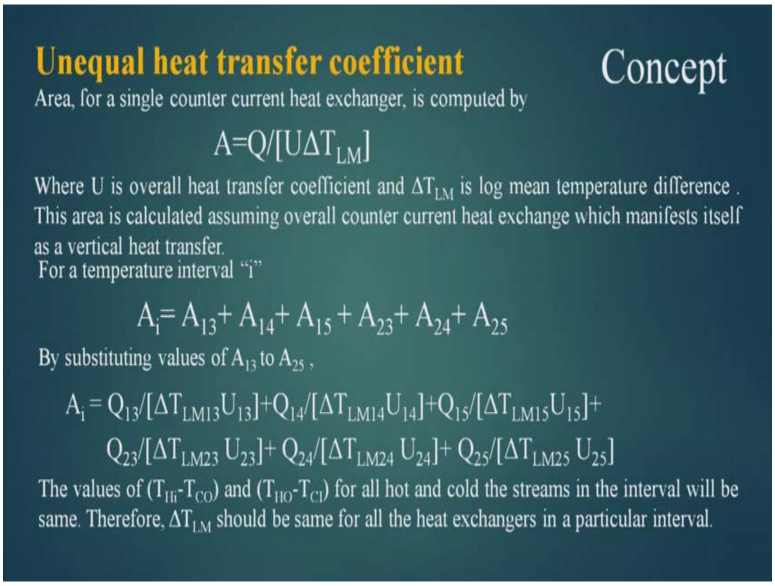

Now, if we adopt this nomenclature and we know that, area is equal to Q divided by U del M, delta T LM, where U is the overall heat transfer coefficient. And delta T LM is the log mean temperature difference. Then, the area calculated will be Ai is equal to A 13, A 14, A 15, A 23, A 24 and A 25 because there are 6 heat exchangers in that ith interval. And if I add up the areas of all these 6 heat exchangers, which are A 13, A 14, A15, A23, A24 and A 25, then this will give me the complete area of the enthalpy interval, I.

Now, by substituting the values of A 13 to A 25 in terms of Q U and delta T LM, we can write down that Ai is equal to Q 13 divided by delta T LM 13, U 13 plus Q 14 divided by delta T LM 14, U 14 plus del Q 15 divided by delta T LM 15, U 15 plus and so on so forth. This would be remembered that, the values of T Hi by T CO and T HO by T CI for all hot and cold streams, in the interval will be the same. Therefore delta T LM should be the same for all heat exchangers in a particular interval.

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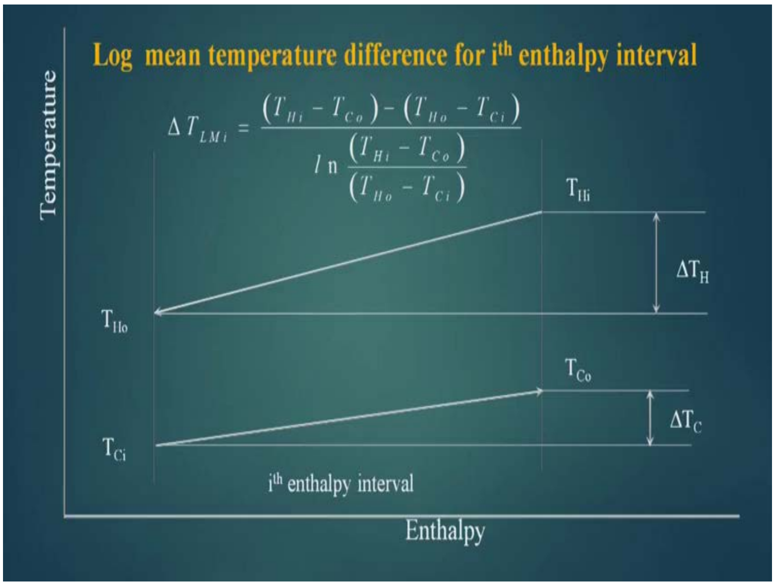

So, this shows how the delta T LM of the ith interval, enthalpy interval and be computed. So, this is delta T Hi minus T CO minus T HO minus T CI divided by this l n T Hi minus T CO, T HO minus T CI.

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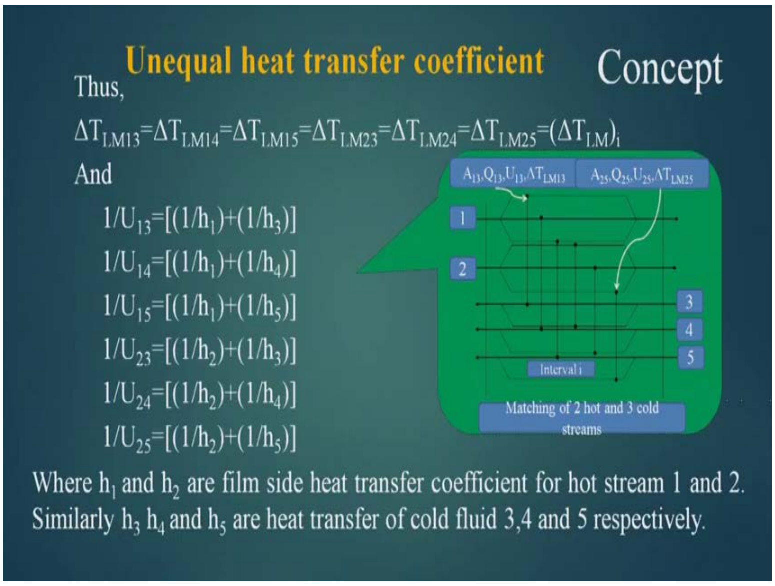

Let us extend the algorithm of the unequal heat transfer coefficient, for area targeting. In the ith interval we have seen that, the delta T LM, that is log mean temperature difference of all streams in the ith interval, are equal. Hence, we can say that delta T LM 13, delta T LM 14, delta T LM 15, delta T LM 23 and delta T LM 24 and delta T LM 25, which are the individual streams delta LM's are equal to delta T LMi. Further, the overall heat transfer coefficients which were U 13, U 14, U 15, U 23, U 24 and U 25 can be now expressed in terms of the individual heat transfer coefficient of the streams.

For example, in this we see that the stream 1, this part of the stream 1 is exchanging heat with this part of the stream 3. And if the overall heat transfer coefficient of this heat exchanger is 1, U 13 then, 1 by U 13 is equal to 1 by h1 plus 1 by h 3. Because, this has 2 streams this heat exchanger, stream 1 and stream 3, even if we spilt a stream into many parts, the heat transfer coefficient of the stream does not change.

That means for stream 1, if this part has got h 1 heat transfer coefficient, this part will also have h 1 heat transfer coefficient. And this part will have also h 1 heat transfer coefficient similarly, for cold stream 3, if this part has got heat transfer coefficient h 3, this part will be also have heat transfer coefficient h 3. So, I can write down 1 by U 13 is equal to 1 by h 1 plus 1 by h 3. Similarly, 1 by U 14 is equal to 1 by h 1 plus 1 by h 4 and so on so forth.

I can express all the overall heat transfer coefficient in this manner, where h 1 and h 2 are film side heat transfer coefficient for hot stream 1 and 2, h 3, h 4, h 5 are the heat transfer coefficient of the cold stream 3, 4 and 5 respectively. Now, if you take the delta T LMi common.

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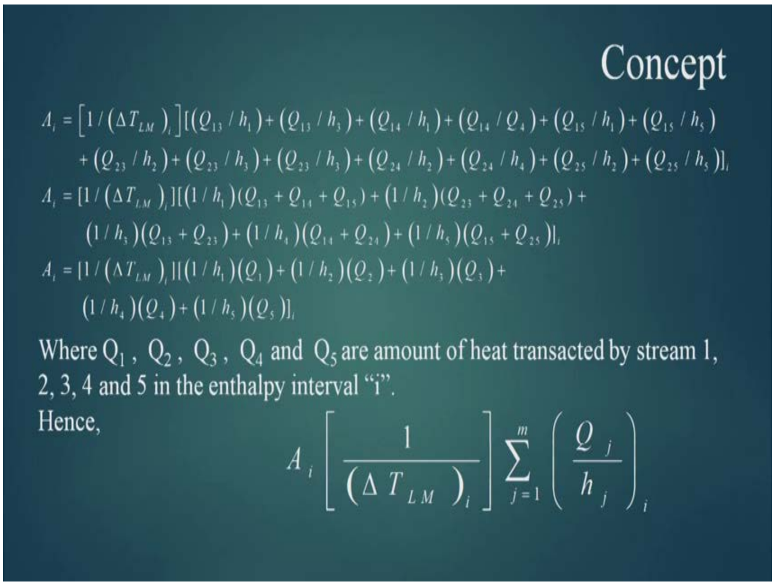

So, 1 by delta T LMi will be equal to Q 13 by h 1 plus Q 13 by h 3 plus Q 14 by h 1 plus Q 14 by h 4, Q 14 by h 4. Similarly, I can express this, then finally, I can find out by solving these equations, that the total heat transfer area of the ith interval will be given by 1 by delta T LMi summation j 1 to m Qj by h j of i.

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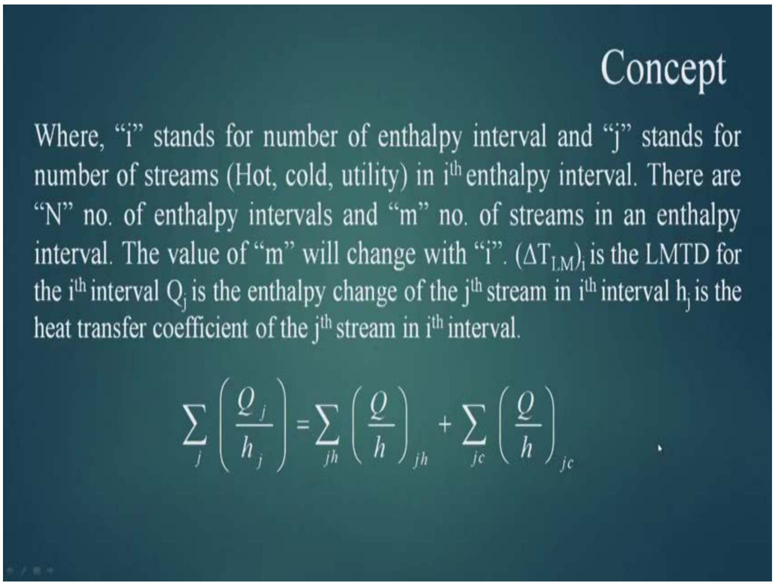

Now, here the, i stands for number of enthalpy intervals and j stands for the number of streams, hot streams, cold streams and utility streams in the ith enthalpy interval. There are n number of enthalpy intervals and there are m number of streams in an enthalpy interval. The value of m, will change with i and delta T LMi is the LMTD for the ith interval and Qj is the enthalpy change for the jth stream in the ith interval. h j is the heat transfer coefficient of the jth stream, in the ith interval. Now, this summation j, Qj by h j can be written by summation Qj h, Q by h j h plus summation on cold streams, number of cold streams jc Q by h jc.

That means I am now separating, the hot streams and cold streams and doing summation individually for hot streams, changing the heat of hot streams and change in the heat divided by the heat transfer coefficient for the cold streams. So, Qj by h j can be written in this fashion when integrations are done for the number of hot streams and number of cold streams separately. Now, we know that the Q can be expressed in terms of the formula Q equal to MCp delta T.

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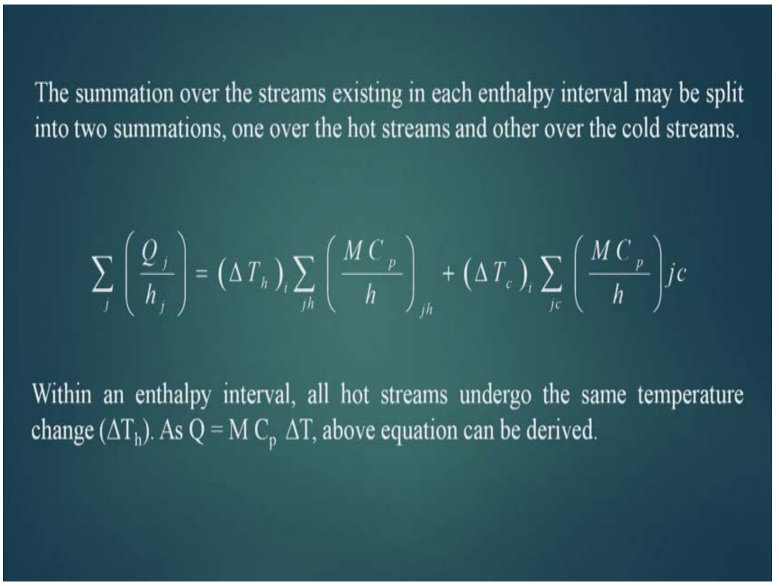

Now, in a ith interval the delta h for all the hot streams are equal similarly, delta C, for the, all the cold streams are equal. Hence, Q j by h j summation j can be written as delta T h for ith interval, summation j h that means, I am summing over the number of hot stream. MCp divided by h for j h plus delta Tc for ith enthalpy interval into summation, over the cold streams j c, MCp by h j c. Within an enthalpy interval, all hot streams undergo the same temperature difference that is, delta T h and all the cold streams also go, undergo the same temperature difference that is delta T c.

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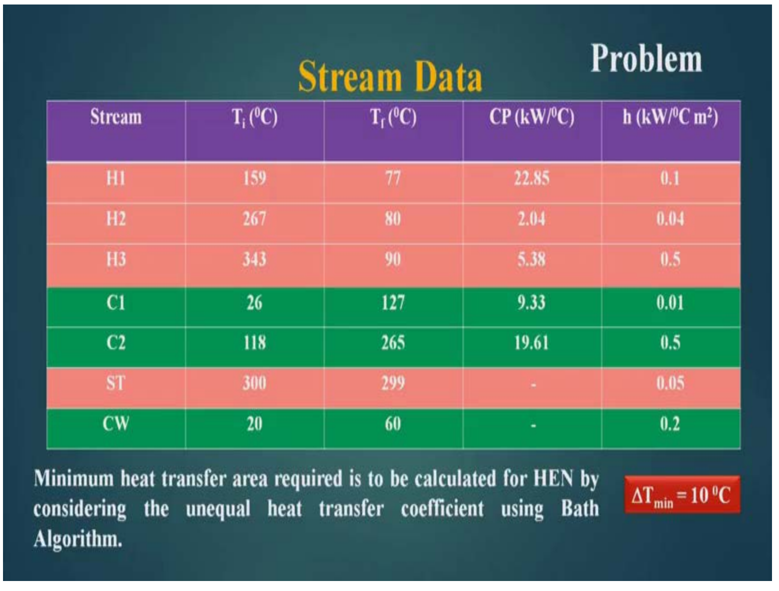

Stream	T_i (^{0}C)	T_f (^{0}C)	CP (kW/^{0}C)	h (kW/^{0}C m^2)
H1	159	77	22.85	0.1
H2	267	80	2.04	0.04
H3	343	90	5.38	0.5
C1	26	127	9.33	0.01
C2	118	265	19.61	0.5
ST	300	299	-	0.05
CW	20	60	-	0.2

Now, if you put this into the equation then, all the above equations which have been discussed up till now, will form an algorithm, in which I have considered the different heat transfer coefficient. That means, the algorithm is applicable to find out the area target under a condition when, the stream heat transfer coefficients are different. To illustrate the algorithm, let us take up a problem, the stream data of the problem is given.

Here you will notice that, with the stream data we have added a new column, which shows the stream heat transfer coefficient of utilities, as well as process streams. Like, for H1 stream the heat transfer coefficient is 0.01, for H2 stream its heat transfer coefficient is 0.04, for H3 stream it is 0.5 and for ST, which stands for steam its heat coefficient is 0.05. And for cold water its heat transfer coefficient is 0.2, for this problem we have taken delta t minimum is equal to 10 degree centigrade.

Now, our requirement is to find out the minimum heat transfer area, please note this, I am going to calculate the minimum heat transfer area, not maximum heat transfer area of the HEN, considering unequal heat transfer coefficient, using bath algorithm. So, whatever the algorithm we have shown you, it is called bath algorithm.

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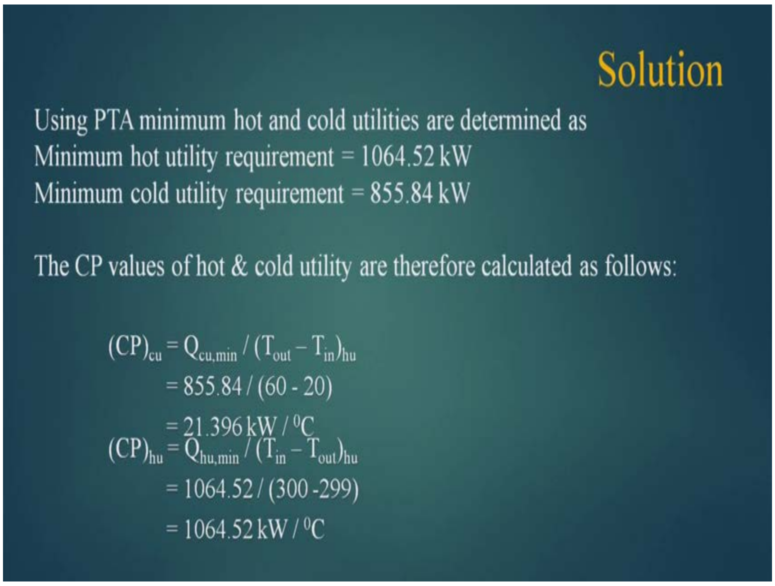

Now once the stream table is available, we can go for problem table algorithm PTA to find out, minimum hot and cold utilities. If we do this, we find that the minimum hot utility requirement is 1064.52 kilowatt, minimum cold utility requirement is 855.84 kilo watt. Now based on these values of hot and cold utilities, we will try to find out what will be the value of CP, capital CP for cold utility as well as hot utility. So, the CP of cold utility will be Q cu minimum, that is the amount of cold utility requirement, divided by T out minus T in of the cold utility.

And this will give rise to 855.84 divided by 60 minus 20 and thus the CP of the cold utility comes to be, 21.396 kilowatt per degree centigrade. For hot utilities specially, when we are using steam, we have to find out what is the temperature of the input steam and what is the temperature of the out.

We know that, steam condenses at a certain temperature and it is a isothermal condensation, but however if you see practically, steam has to move from one point to another point. That means, there is a temperature or there is a pressure gradient which will allow the steam to flow from one point to another point. This clearly indicates that, the steam will not condense at a constant pressure, but will condense at a differential pressure.

That differential pressure may be very less so here we assume that the temperature of the steam input steam is 300, as given in the table, but the T out of the steam is 299, which is 1 degree less than, the T in. When we are doing this, we are not committing any mistake because we are in thermal balance and the CP of the hot utility what we calculate will take care of this.

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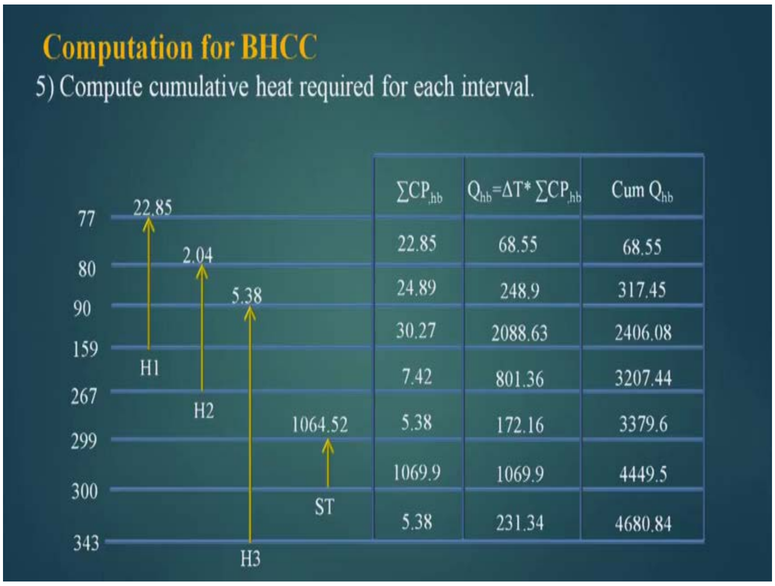

In this case, the CP of the hot utility calculate is 1064.52 kilowatt once the CP's of this are known, we can plot the hot and cold temperatures in ascending order. So, we are going to compute the balanced hot composite curve and that is why, we will only take the data from the stream table, which is related to the hot streams, that is H1, H2 and H3 and the steam, which is the hot utility. So, when we consider the supply and target temperature of these streams, we find that 77 is the minimum temperature of the hot streams including hot utility. And 343 is the highest temperature now, we write down the corresponding CP values for the hot streams and hot utility, according to their temperature intervals.

So, H1 stream moves from 159 degree centigrade to 77 degree centigrade and its CP value is 22.85. Hot stream H2 moves from 267 to 80 degree centigrade, its CP value is 2.04. And H3 which is the hot stream 3, is moving from 243 to degrees centigrade to 90 degree centigrade and its CP value is 5.38 and the steam which is from 300 to 290 degrees, 99 degrees centigrade, its CP value is 1064.52. Now, we will compute the cumulative CP values in different temperature intervals. Now, in this temperature interval 80 to 77 degree, only H1 is present and the CP value of H1 is 22.85 and that is why, in this temperature interval the cumulative CP value is 22.85.

However, from 90 to 80 degree temperature interval there are 2 streams H1 and H2 and the CP value, the summation of the CP value will be 22.85 plus 2.04. So, it becomes 24.89 similarly, in this interval 90 to 159 there are 3 hot streams present. So, the summation CP HP will be the summation of all these 3 quantities. So, we see here CP value is 30.27, here from 267 to 159 only two hot streams are available, the summation CP will be 2.04 plus 5.38, which comes out to be 7.42, in this temperature interval only H3 is working so CP value will be 5.38, in this temperature interval H3 plus this steam is working.

So, the CP value will be combination of these two figures, comes out to be 1069.9, in this temperature interval 343 to 300, only one stream is working H3. And hence its CP value is 5.38, then after computing this we will find out, the heat required for each interval Q hb, which is equal to delta T into summation of the CP values. So, this will be delta t here 80 and 77, which is 3, 3 into 22.85 so this is equal to 80 minus 77 into 22.85 is 68.55.

So, this goes here similarly, we can fill up the heat required for each interval and you should remember this, this is all we are doing for hot stream and hot utility. And we are computing data for BHCC and once this data is ready, we will plot balanced hot composite curve. Now, we plot the cumulative heat required for each interval so the first interval will be 68.55, the second interval will be this, plus this and for the third interval this, will be this plus this, plus this. So, we have filled up the cumulative heat required for each interval.

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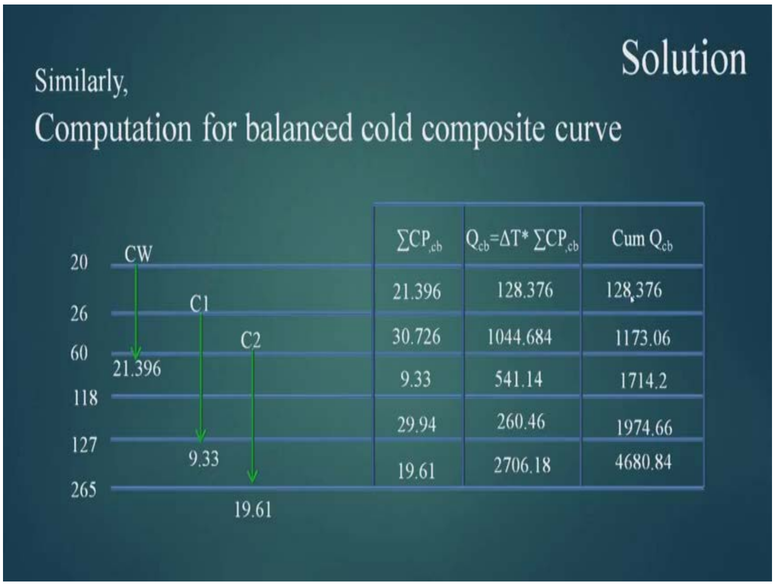

Now, we will see how to compute the data for balanced cold composite curve, for balanced cold composite curve, we will select from the stream table, the data for cold streams, that is C1 and C2 and cold utility. The temperature levels are written here as from 20, 26, 60, 118, 127 and 265 in the increasing order, the cold utility CW goes from 20 degree centigrade to 60 degree centigrade, to its CP, capital CP is 21.396.

C1 moves from 26 to 127 degree centigrade, its NCP value is 9.33 and the C2 goes from 60 degree to 265, its NCP value is 60 to 265. Now, we compute this summation of CP values, in different temperature intervals now, in the first interval it is 26 to 20 and only the cold utility is working. So, here 21.396 will be written so it is 21.396 however, for this 60 to 26 temperature interval, two streams are working C1 and CW so this value will be summation of this and this value. Similarly, in the third temperature interval this is

118 to 60, two cold streams are working so here the value will be summation of this and this.

And for the last temperature interval, this is 19.61, as only this stream is working so once this is available to us, we can compute Q cb, which is delta t into summation of the Cp's of the interval. Here the summation is 21.396 the temperature difference is 6 degree, that is 26 minus 20 so 6 into 21.396, will give you 128.376 similarly, for this temperature levels interval, from 60 to 26. So, delta T is 60 minus 26 into the CP value 30.726, this comes out to be 1044.684 similarly, we have filled up this.

Now, we will fill up the cumulative cb values, this is the, for the first interval this value is 128.376, for the second interval this is the summation of this value and this value which is 1173.06. For this interval, this is the summation of this value, this value and this value. So, it comes out to be 1714.2 so similarly, we fill up this column also. Now, the data is ready for balanced composite curve, we have created data for the cold balanced, cold composite curve as well as balanced hot composite curve.

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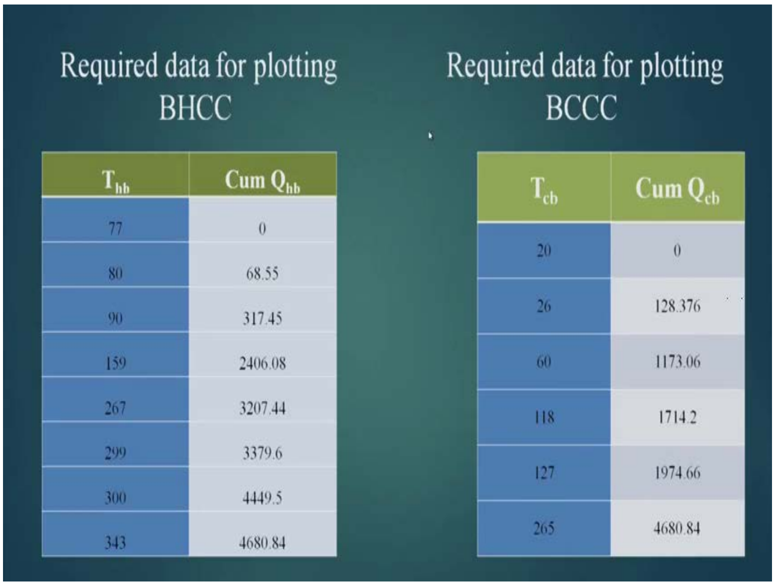

T_{hb}	Cum Q_{hb}
77	0
80	68.55
90	317.45
159	2406.08
267	3207.44
299	3379.6
300	4449.5
343	4680.84

T_{cb}	Cum Q_{cb}
20	0
26	128.376
60	1173.06
118	1714.2
127	1974.66
265	4680.84

So, this is the hot composite curve data and this is the cold composite curve data, this is available for us.

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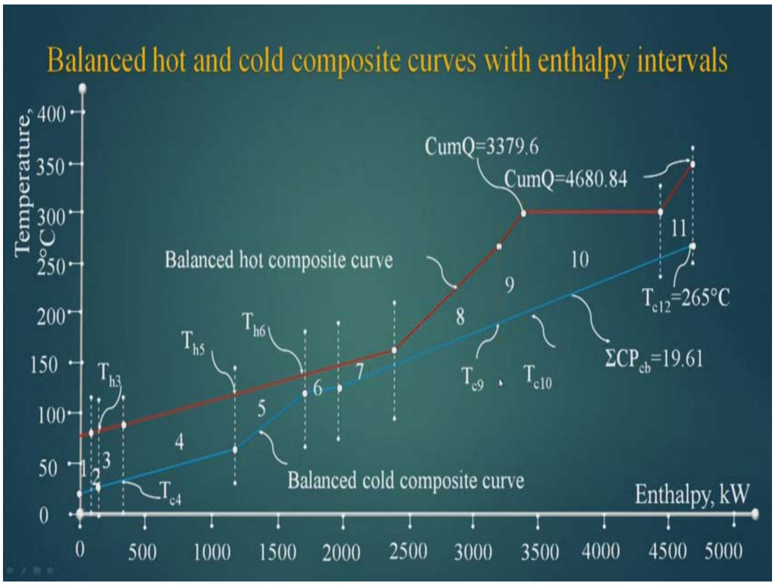

Now, you can plot them so this is my cold composite curve, balanced cold composite curve, this is my balanced hot composite curve. Now, these are the points where this line is changing slope, here the line is changing slope, here the line is of the cold balanced cold composite curve is changing slope. Here the balanced hot composite curve is changing slope, here the balanced cold is changing the slope so on so forth. Now what we see that thought the temperature here is known, the corresponding temperature at the cold balanced cold composite curve is not known. Similarly, here the temperature of the balanced cold composite is known, but corresponding temperature at the hot balanced composite curve, which is this point is not known.

Now, if I consider this to be enthalpy intervals and I want to find out the area of this enthalpy interval, I should known all the four temperatures. Out of these four temperatures, only two temperatures are known and rest two are not known. However one thing we get it here, it is a straight line relationship so we can use the technique of linear interpolation, to find out the temperature here. So, we will see that, that how this technique should be used, here we will see that this can be divided into 11 enthalpy intervals.

And here we see, there is some temperature which has not known like, T c12 is not known, T c10 which is corresponding to this is not know, T c9 is also not known, but we know this CP, summation CP value of this interval. So, based on this CP values we can calculate, the temperatures using the linear interpolation method. So, these values are not known. So, we have to compute these values.

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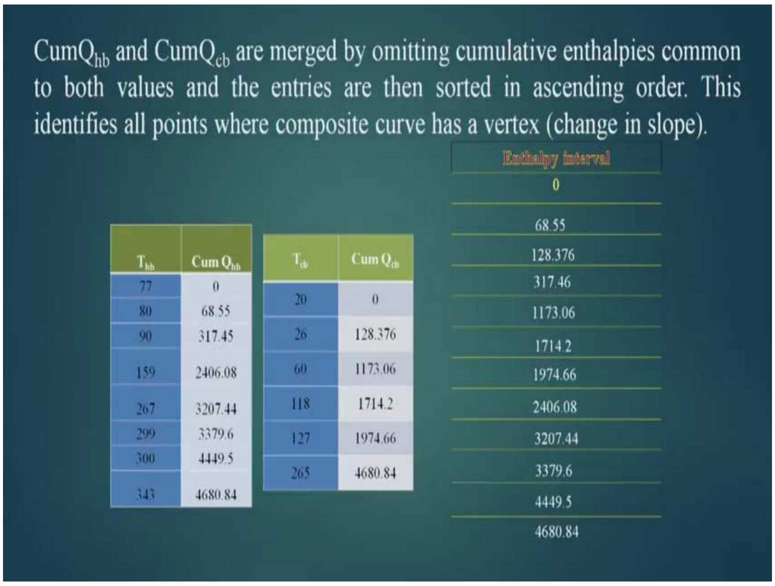

Cumulative Q hb and cumulative Q cb are merged, by omitting cumulative enthalpies common to both values and the entries are then stored in ascending order. This identifies all the points where composite curve has a vertex. Now, from these two tables of which one is for balanced hot composite curve and this is for balanced cold composite curve, we will note down the enthalpy cumulative Q hb and Q cb values. So, this value and these values are merged together and they are sorted in ascending order.

If two values match, we take one out of it, we have already computed all the data required for the plotting of balanced hot composite curve and cold composite curve. Now, the job left is to find out the temperatures of those areas or those points, where for balanced hot composite curve the temperature is not known. And those areas where the, for the balanced composite curve for cold the temperatures are not known. We will see here.

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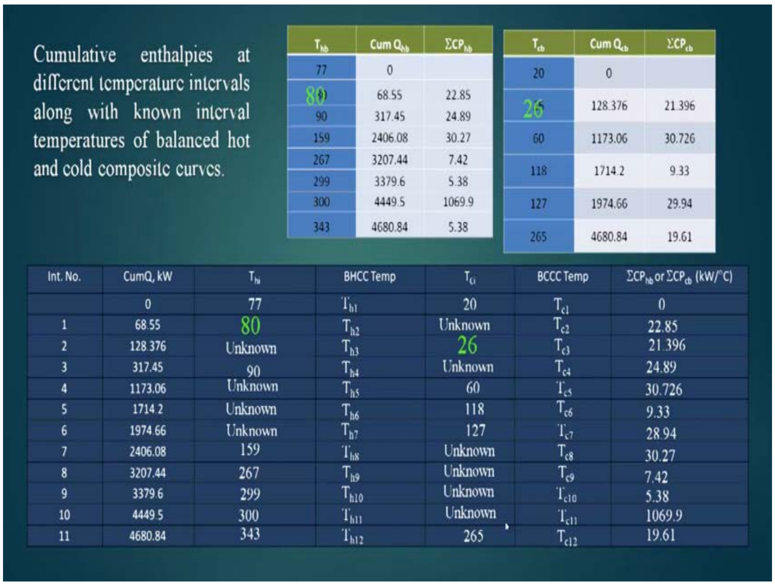

Now, here it is T hi is given and we clearly see there are some enthalpy intervals where temperatures are not known for hot. Similarly, for cold there are some intervals where cold temperature is not known. Now, we will fill up the summation of CP hp and or summation of CP cold in those areas where either its value is available for hot or its value is available for cold. Like for example, at 80 degrees centigrade of hot stream temperature, the value of C summation of this CP hb is available, which have been taken from here.

Similarly, for 26 degree centigrade of the cold the value of summation CP cb is taken here, as 21.396. That means, wherever the temperatures are available we have taken the values of the summation of CP hb or CP cv, wherever possible. Now, let us see that what are the temperature which are not available to us, like this temperature for the hot is unknown, this temperature for the hot is unknown, this temperature of the hot is unknown, this temperature is unknown.

However, these temperatures are available similarly, for the balanced cold composite curve, this temperature is unknown, this temperature is unknown and these are the temperatures, which are unknown. Now our job is to find out, these unknown temperatures and the method which we will be employing for finding out the unknown temperatures, is the linear interpolation. Because, the segments of the balanced hot composite curve or the balanced cold composite curves are straight lines and hence, we can very effectively use the linear interpolation technique to find out the temperatures.

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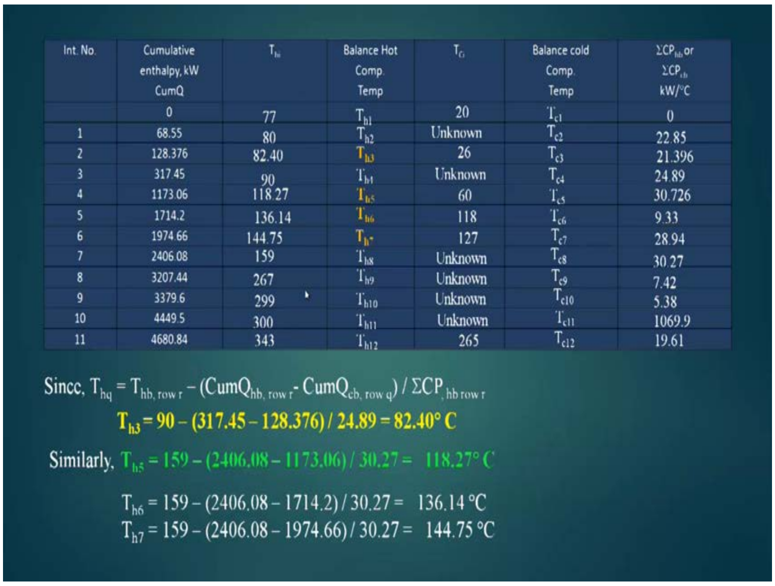

Now, the temperature which are not known are given in this color, for the hot. Similarly, we will find out the temperatures which were not known, given in the balanced cold composite curve in the green color. So, let us see how to find it out now, this is the equation using, using which we will be finding out the unknown temperatures.

The explanation is given here, but it is better to go through the method to understand it. Now, to start with we will try to find out the unknown temperature here, which is T h3, now T h 3 is given by using these temperatures and cumulative enthalpies and summation of delta CP values. Now, we shown that I want these temperatures so the below temperature is given which is 90. I have written it 90, then corresponding to this temperature the cumulative Q is 317.45, taken 317.45 then were deducted this value.

Here 128.376, then we have divided this with the summation CP values, which is available here. So, it gives 82.40 as the unknown value so these moves to unknown value here, now similarly, another temperature which is T h5, is also not known. So, we calculate T h5 here so if you see the T h5, then we will be using these four values to compute T h5. Now, if you see, if you want to find out this temperature the next known temperature is this 159 because these two temperatures are also unknown.

So, there is no information available about the temperature, in this two temperature intervals. So, the known temperature is here 159 so you take 159 minus the enthalpy here is 2406.08, we have taken this, then minus the enthalpy which is known here, is this. The unknown level is this so we have taken this then divided by the NCP value, summation NCP value which is available here, on this row.

So, this is o118.27 so moves to that and can sit up 118.27 similarly, these two unknown values are also computed based on linear interpolation technique. Now, we have completed the unknown temperature values, for the computation of area target for hot balanced hot composite curve. The same thing has to be repeated for the balanced cold composite curve.

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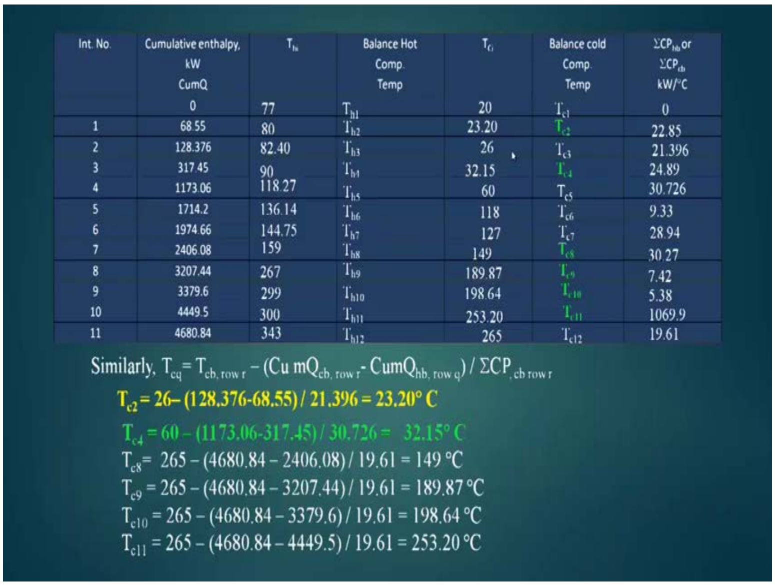

So, the same type of equation is used here to compute the unknown temperatures of the balanced cold composite curve. This is the unknown temperature which is T c2, unknown temperature T c4, unknown temperature T c8, T c9, T c10 and T c11. So, the first attempt would be taken to compute the T c2 values so T c2 is equal to 26 minus so these are the temperatures cumulative enthalpy and summation CP values, which we will be using. So, this is equal to 26 because this is the unknown value next value is 26 so 26 minus this value 128.376 minus this value, divided by the summation of CP values available here. So, it is 23.20 so it moves to the, this place and it becomes 23.20 value.

Similarly, the unknown values here, here, here, here, here, here are computed and transferred so the second. So, these are the values which will be used on 60 minus we are computing this value unknown value that is T c4. So, this is 60 minus this cumulative value and then minus this value, then divided by in this 2, the value of summation CP. So, the calculated temperature is 32.15, it moves to here similarly, this four values are also computed and filled up.

Now, we are able to compute all the unknown temperatures of the balanced hot composite curve and all the corresponding temperatures in the balanced cold composite curve. And this is required to find out the LMTD, for all the enthalpy intervals of the balanced composite curve so this work is now finished. So, we will go for computation of area.

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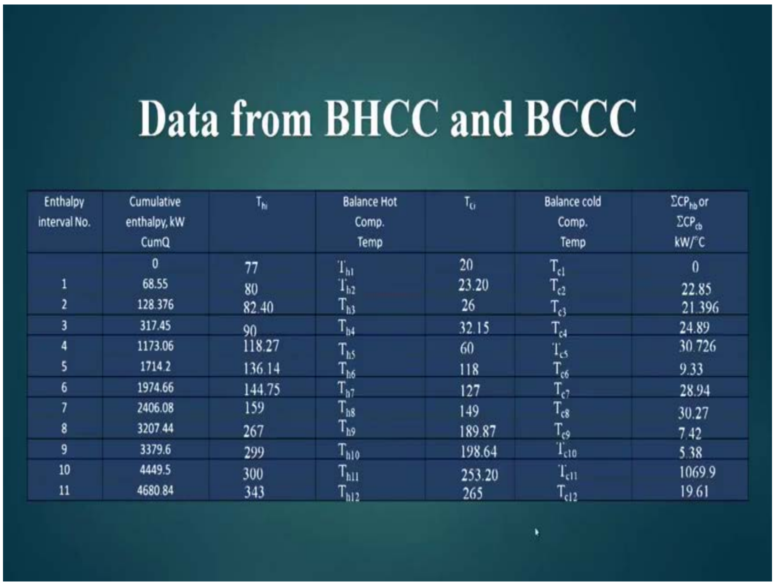

Data from BHCC and BCCC

Enthalpy interval No.	Cumulative enthalpy, kW CumQ	T_{hi}	Balance Hot Comp. Temp	T_{ci}	Balance cold Comp. Temp	ΣCP_{hb} or ΣCP_{cb} kW/°C
	0	77	T_{h1}	20	T_{c1}	0
1	68.55	80	T_{h2}	23.20	T_{c2}	22.85
2	128.376	82.40	T_{h3}	26	T_{c3}	21.396
3	317.45	90	T_{h4}	32.15	T_{c4}	24.89
4	1173.06	118.27	T_{h5}	60	T_{c5}	30.726
5	1714.2	136.14	T_{h6}	118	T_{c6}	9.33
6	1974.66	144.75	T_{h7}	127	T_{c7}	28.94
7	2406.08	159	T_{h8}	149	T_{c8}	30.27
8	3207.44	267	T_{h9}	189.87	T_{c9}	7.42
9	3379.6	299	T_{h10}	198.64	T_{c10}	5.38
10	4449.5	300	T_{h11}	253.20	T_{c11}	1069.9
11	4680.84	343	T_{h12}	265	T_{c12}	19.61

So, this values are filled up here we will use this table to compute the area target.

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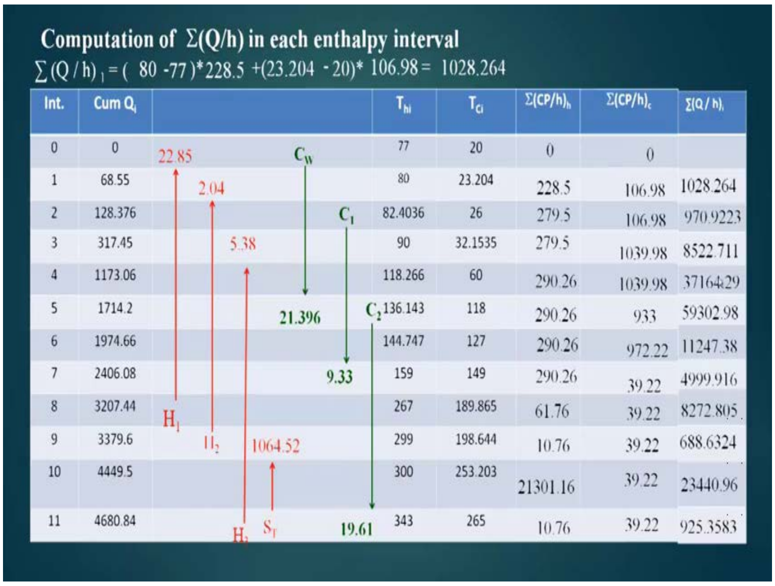

Computation of $\Sigma(Q/h)$ in each enthalpy interval

$\sum(Q/h)_1 = (80-77)*228.5 + (23.204-20)*106.98 = 1028.264$

Int.	Cum Q_i		T_{hi}	T_{ci}	$\Sigma(CP/h)_h$	$\Sigma(CP/h)_c$	$\Sigma(Q/h)_i$
0	0	22.85 C_W	77	20	0	0	
1	68.55	2.04	80	23.204	228.5	106.98	1028.264
2	128.376	C_1	82.4036	26	279.5	106.98	970.9223
3	317.45	5.38	90	32.1535	279.5	1039.98	8522.711
4	1173.06		118.266	60	290.26	1039.98	37164.29
5	1714.2	21.396 C_2	136.143	118	290.26	933	59302.98
6	1974.66		144.747	127	290.26	972.22	11247.38
7	2406.08	9.33	159	149	290.26	39.22	4999.916
8	3207.44	H_1	267	189.865	61.76	39.22	8272.805
9	3379.6	H_2 1064.52	299	198.644	10.76	39.22	688.6324
10	4449.5		300	253.203	21301.16	39.22	23440.96
11	4680.84	H_3 S_1 19.61	343	265	10.76	39.22	925.3583

Now, for computation of the area target, we will have summation CP divided by h values for hot and summation CP by h cold values, for cold. These are our streams and these are the heat transfer coefficient available for different streams like, for H1 the heat transfer coefficient is 0.1, for H2 it is 0.04, for H3 it is 0.5. And for the steam it is 0.05, for cold quarter this is 0.2 and so on so forth. So, we have to fill up these two columns.

Now if I see for this interval, only one hot stream is working that is H1. So, the summation CP divided by h can be computed as for interval 1, CP h for interval 1 is this value. Now, divided by the h that is heat transfer coefficient of this stream H1, which is 0.01. So, we divide this by 0.01 and find out the value to 228.5 now for the second, this goes to here 225, 228.5 and for the this interval, we have two streams which are working.

So, we have already computed for this stream so we will use this result and then we will newly calculated for this streams, that means 2.04 divided by 0.04 and we then, add then up this with the value ,which we compute for this stream. The total will be written here so let us see for stream interval 2, for enthalpy interval 2 this value will be summation of this value will be equal to, we plus it. This value divided by the heat transfer coefficient of the second stream and we add this 2.

We get this 279.5 that moves here similarly, for this 3, here we have two streams working for this fourth, we have three hot streams working here and for here, we have two hot streams. That means one hot stream is H3 and the utility stream is working so we can find out the summation CP by h values for hot in those intervals and we can fill it up. Similarly, we can go for the cold one, if I see the interval number 1, then only the cold water stream is working, its CP value is 21.396 and the h value is 0.2.

So, this value becomes 106.98 which is 21.396 divided by 0.2 so this value I get now in the second interval, the same cold water stream is there, that is cold utility stream. So, the value is the same 106.98 because it is not changing whereas, in the third interval there are two cold streams.

So, my value will be 21.396 divided by 0.2 plus 9.93 divided by 0.01, when I add them together, I get a value 1039.98. Now similarly, this column has been filled now, we are interested in finding out what is the Q by h value because Q by h value is needed for the computation of h. So, Q by h is computed as the differential in temperature now, what it is that it is 80 minus 77, these two 80 minus 77 into the value 228, which is this plus then 23.204 minus 20 this ism these are delta T values into summation CP values.

So, this is multiplied 106.98 and when we add this two terms, we get 1028.264, in this Q by h term, the Q for the cold as well as Q for the hot is considered and that is why we are adding two terms. So, this result goes here similarly, for the next we can compute and we can fill up this Q by h values.

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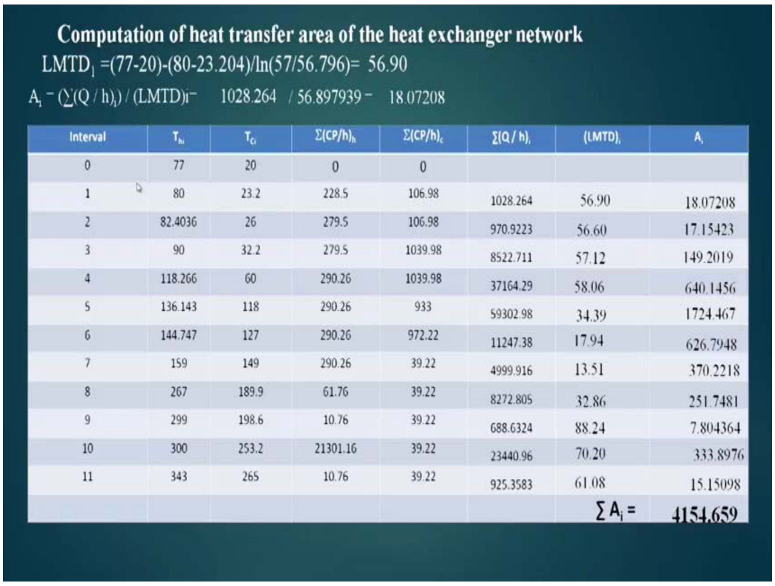

Interval	T_{hi}	T_{Ci}	$\Sigma(CP/h)_h$	$\Sigma(CP/h)_c$	$\sum(Q/h)_i$	$(LMTD)_i$	A_i
0	77	20	0	0			
1	80	23.2	228.5	106.98	1028.264	56.90	18.07208
2	82.4036	26	279.5	106.98	970.9223	56.60	17.15423
3	90	32.2	279.5	1039.98	8522.711	57.12	149.2019
4	118.266	60	290.26	1039.98	37164.29	58.06	640.1456
5	136.143	118	290.26	933	59302.98	34.39	1724.467
6	144.747	127	290.26	972.22	11247.38	17.94	626.7948
7	159	149	290.26	39.22	4999.916	13.51	370.2218
8	267	189.9	61.76	39.22	8272.805	32.86	251.7481
9	299	198.6	10.76	39.22	688.6324	88.24	7.804364
10	300	253.2	21301.16	39.22	23440.96	70.20	333.8976
11	343	265	10.76	39.22	925.3583	61.08	15.15098
						$\sum A_i$ =	4154.659

Now, the next is to compute LMTD because we know the temperatures, the extreme temperatures, extreme even and extreme odd temperatures. So, four temperatures are needed to compute LMTD value so we see that we find out the LMTD value, for interval 1. So, for this the LMTD value is this, this is 77 minus 20, 77 minus 20, then 80 minus 23.2, then ln, this divided by this, which comes out to be 56.90.

We are using these four values to compute this LMTD similarly, for this we can use this and this and this and these values, to compute LMTD and we can fill it, the LMTD values here. Then, area can be calculated because area is summation Q by h divided by the LMTD for each interval so for interval 1 we have Q by h values for this and LMTD value for this. So, we can divide this value 1028.264 divided by 56.90.

So, we get this value 18.07 so similarly, we fill it this column and when we add this, I get the area because now I have calculated the area of each interval. And when I add this on, I get the total area of the heat exchanger network, which includes heaters and coolers. So, my final result is total area which is 4154.659 meter square now, this area is the minimum area.

After these lectures, we will take the area targeting part 2, in which we will discuss if the heat transfer coefficient of all the streams are same then, how to compute the minimum area, using the bath algorithm. And then we will discuss, that in which condition bath algorithm will give minimum area and in which condition, there will be a departure of minimum area. That means, it will not give minimum area and it will give more area and then, we will discuss, what are the other alternatives available for area targeting which will lead to minimum area.

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These are the references.

Thank you.