Process Integration
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Module - 4
Targeting
Lecture - 9
Cost Targeting – Part 01

Welcome to the lecture series on Process Integration. This is module-four, lecture number nine. The topic of today's lecture is cost targeting.

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In this lecture, we will introduce the cost targeting, we will talk about capital cost targeting then operating cost targeting and finally, the total cost targeting, which involves the capital cost targeting and operating cost targeting for a HEN.

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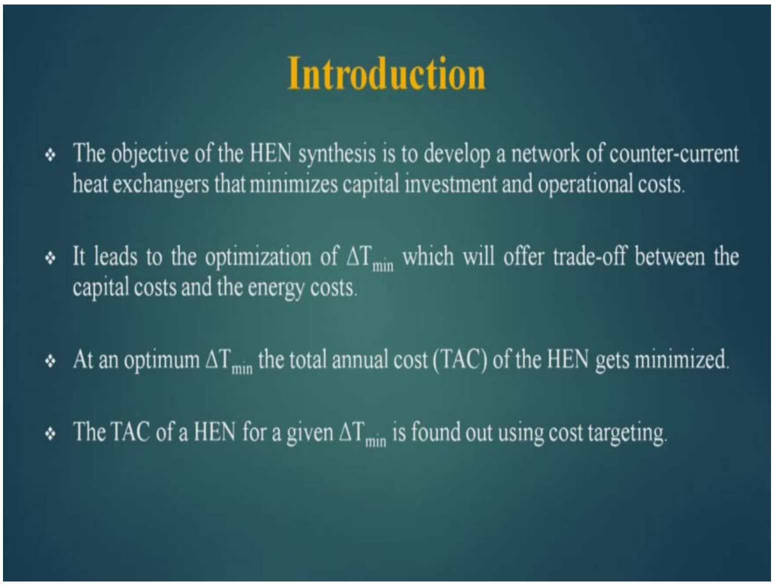

The objective of the HEN synthesis is to develop a network of counter-current heat exchangers that minimizes capital investment and operational costs. When a problem of heat transfer is given then the quantity of heat transfer is known, and based on this quantity a heat exchanger network has to be designed, though the quantities not known exactly, but roughly the quantities known. Now we have to develop a heat exchanger network, which will have less cost than others, because in pinch analysis a number of heat exchanger networks can be design to satisfy the operational constraints. But what heat exchange network we should select, we should select that heat exchanger network which will operate with minimum capital investment and operational cost.

To know this, the cost targeting is necessary because when we design the heat exchanger networks. We have to target its cost, that is capital cost and operational cost, and will select that heat exchanger network which will have minimum. It leads to the optimization of delta T minimum which will offer trade-off between the capital cost and the energy costs. It needs a lot of discussion, we have seen that a heat exchanger network is design for a certain delta T minimum. And what delta T minimum, we should take for the design of the heat exchanger network. We have seen that in the problems, we have assumed the delta T minimum. The caution is whether the assumed delta T minimum is correct or not.

So, what is being done that for they different delta T minimum HENs are designed and then cost targeting of those HENs are done. Then we find that at a certain value of delta T minimum, which is called delta T minimum optimum. The TAC, which is total annual cost of the heat exchanger network is minimum and that delta T minimum optimize considered. And optimum delta T minimum, the total annual cost TAC of the HEN gets minimized. The TAC of a HEN for a given delta T minimum is found out using cost targeting.

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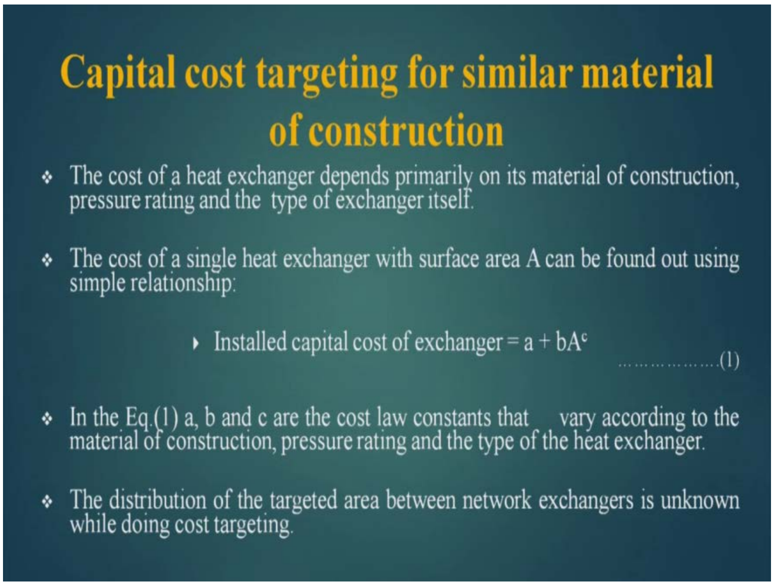

Now let us see about the capital cost targeting of similar materials of construction. Now we can divide the cost targeting into two parts. When the HEN is made up of similar materials of construction, that means if all the heat exchangers in the heat exchanger network are say made up of mild steel then cost targeting will be differently done. But when the materials differ, that means, some materials are of say stainless steel, other materials or of titanium other materials of MS, so if the materials change or the design changes that means some heat exchangers are for high pressure, some are for low pressure then capital cost targeting will be done in different way.

In this lecture, we will see both the ways of cost targeting. Now to start with will do cost targeting for similar materials of construction. The cost of a heat exchanger depends primarily on its material of construction, pressure rating and the type of heat exchanger itself. The cost of a single heat exchanger with surface area a can be found out using simple relationship. Installed cost of the heat exchanger is equal to a plus b A to the power c. Where a is the area of the heat exchanger; the above equation a, b and c are the cost law constants that vary according to the material of construction pressure rating and type of heat exchanger.

The distribution of the target area between network exchanger is unknown while doing the cost targeting. What it tells that if you are designing a HEN, and say ten number of heat exchangers are there in the HEN, it is difficult to say that all the ten heat exchangers will have equal area, they will have different areas. And hence this problem many a times creates problem in capital cost targeting, because the equation which we have used a plus b A to the power c works well in a narrow range of area.

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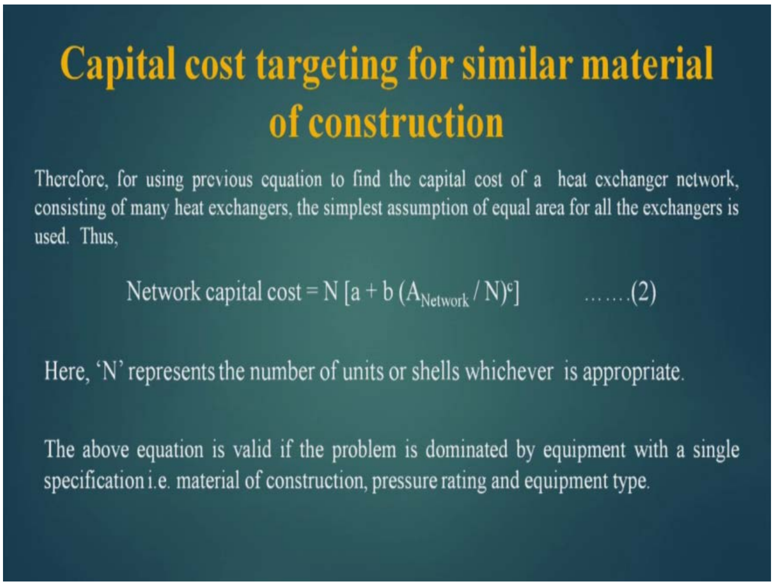

Therefore, for using previous equation to find the capital cost of a heat exchanger network, consisting of many heat exchangers. The assumption is taken up equal area of all the heat exchangers. So, what is basically done, the network capital cost, that means, heat exchanger network capital cost is equal to number of units in the brackets a plus b A network divided by N to the power c. Where A network means the area of all the heat exchangers sum together in the network, and N is the number of units in that network; that means, number of heat exchangers in that networks or number of shells in that network, whichever is appropriate.

We have already conducted the units target and shells target. So, from the units target the value of N is known; and from the shells target the value of total shells available in the heat exchanger network is known. So, it is not difficult to find out N value. The above equation is valid, if the problem is dominated by equipment with a single specification that is material of construction, pressure rating and equipment type. So, this is the drawback of this equation of capital cost targeting. And if some of the material of construction, pressure ratings and equipment type of changing then this equation will give error.

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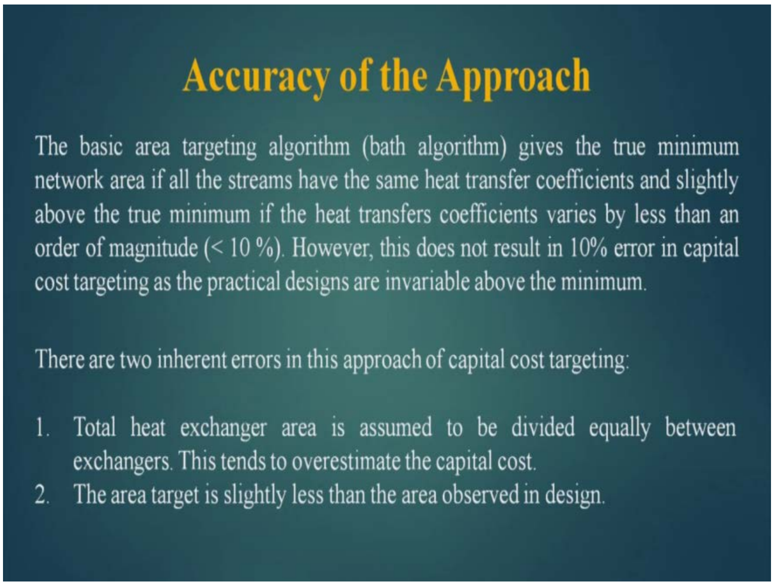

The basic area-targeting algorithm the bath algorithm gives the true minimum network area if all the streams have the same heat transfer coefficient and slightly above the minimum if the heat transfers coefficients varies by less than an order of magnitude that is 10 percent. We have gone through the area targeting procedure, there we have use bath algorithm. The bath algorithm will give minimum area of the heat exchanger network, if the heat transfer coefficients of the streams are almost equal or slightly changing with in error margin of say 10 percent. However, this does not result in 10 percent error in capital cost targeting as the practical designs are invariable above the minimum.

If the heat transfer coefficients are changing are not within a band of 10 percent or so, the area offered by the bath algorithm will be higher. And so in most of the area targeting, the area which we find out is more than the minimum area. There are two inherent errors in this approach of capital cost targeting. The total heat exchanger area is assumed to be divided equally between the exchangers. This trends tends to overestimate the capital cost. And the second problem is that the area target is slightly less than the area observed in design.

Now we will see that when we are targeting a area of a heat exchanger network this is the minimum area, which we are targeting. But when we design we find back, the total area of the design is little bit more than the minimum area which we have targeted by area targeting method. So, area targeting method gives the bottom line. When we design then we are above this bottom line and hence some errors will creep into this equation.

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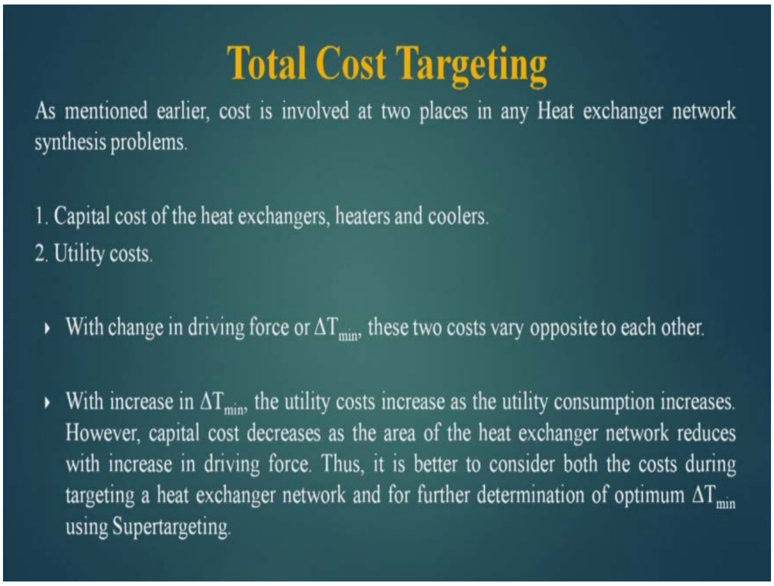

As mentioned earlier cost is involved at two places in any heat exchanger networks synthesis problems. The first cost is capital cost of the heat exchangers, heaters and coolers. Then we design the heat exchangers, which exchange process-to-process heat then that is a cost involved in the manufacturing of this heat exchangers, heaters and coolers, and that cost is called capital cost. Once we design and manufacture the heat exchanger, its operating life is many years, say ten years also. So, the capital cost which we are investing it is for a longer duration, and it is for a duration of the operating life of the heat exchanger.

The another cost is utility cost. In a heat exchanger network will be using utilities; hot utilities and cold utilities. And the consumption is continuous, so a cost is also involved in purchasing those utilities or handling those utilities. With changing driving force delta T minimum, there are two costs vary opposite to each other. As I have already told you that the area is a function of delta T minimum that means area of the heat exchanger network is a function of delta T minimum. So, when we change delta T minimum, we have to see that what is the trend in change in the capital cost, and what is trend in change in the utility cost. We will see that both costs vary opposite to each other. If it is so, then it is a perfect case of optimization that means, a delta T minimum optimum will be available, which will give me the minimum total annual cost of the heat exchanger network.

With increasing delta T minimum, the utility cost increase just as the utility consumption increases. This we have already seen in energy targeting that if I increase delta T minimum the amount of hot utilities as well as cold utilities will increase and hence the utility consumption will increase. However, the capital cost decreases as the area of the heat exchanger network will decrease due to the increase in driving force. We know that is the equation which is tell Q equal to U A delta T Lm. And this clearly tells that if I increase the delta T minimum then the driving force for heat transfer increases, and hence it will require lower amount of area to transfer the same amount of Q. Thus it is better to consider both the cost during targeting a heat exchanger network for the further determination of optimum delta T minimum using super targeting. When we optimize delta T minimum as the function of TAC then this process is called super targeting.

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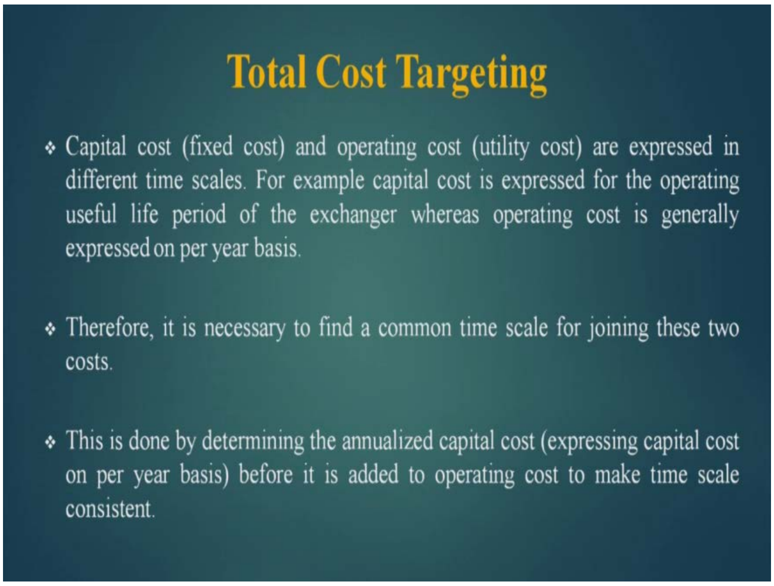

The capital cost or fixed cost and operating cost which is a utility cost, all it is a pumping cost or a mixed up this two are expressed in different time scales, this is very important. The fixed cost is expressed for the full operating life of the heat exchanger, whereas the operating cost is expressed on yearly basis, so the time scales are different and hence we cannot had them. For example, the capital cost is express for the operating useful life period of the heat exchanger whereas the operating cost is generally expressed per year basis. Therefore, it is necessary to find a common time scale for joining these two costs. And what will be that common time prime, this is done by determining the annualized capital cost and the annualized capital cost is expressing cost, expressing the capital cost per year basis before it is added to operating costing to make the time scale consistent.

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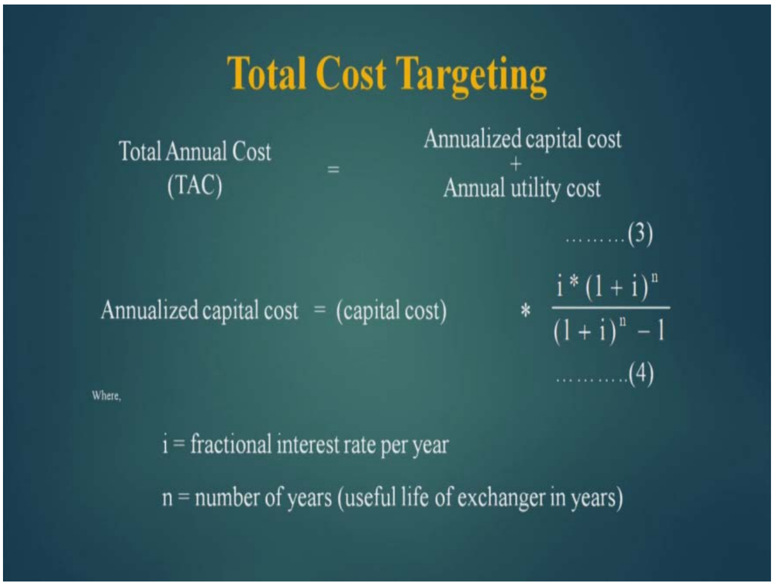

The annualized capital cost is equal to capital cost into i into in brackets 1 plus i to the power n divided by in brackets 1 plus i to the power n minus 1. So, this is the factor which is has to be multiplied with the capital cost to convert the capital cost to annualized capital cost. So, the total annual cost - TAC is equal to annualized capital cost plus annual utility cost. So, here we have added both the cost that is capital cost and utility cost to form a factor, which is called total annual cost. Here the i is the fractional interest rate per year, and n is the number of years that is the useful life of the exchanger in years.

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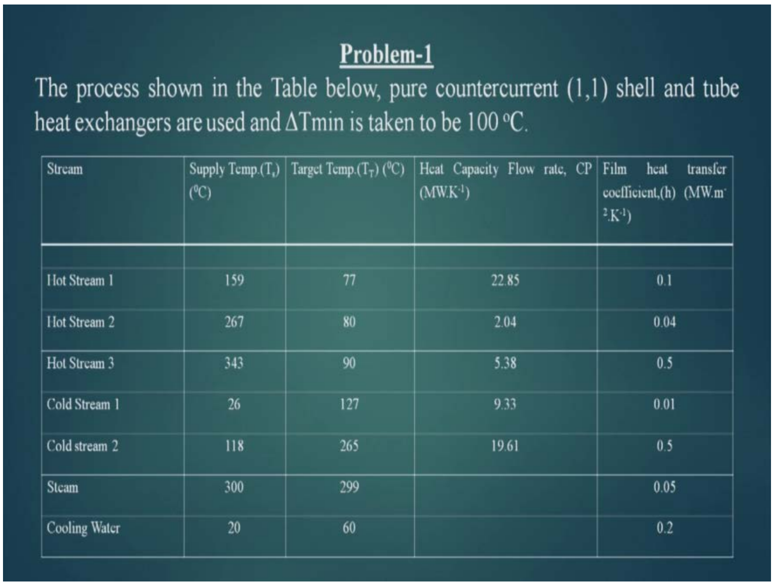

Stream	Supply Temp.(T_s) (°C)	Target Temp.(T_T) (°C)	Heat Capacity Flow rate, CP ($MW.K^{-1}$)	Film heat transfer coefficient,(h) ($MW.m^{-2}.K^{-1}$)
Hot Stream 1	159	77	22.85	0.1
Hot Stream 2	267	80	2.04	0.04
Hot Stream 3	343	90	5.38	0.5
Cold Stream 1	26	127	9.33	0.01
Cold stream 2	118	265	19.61	0.5
Steam	300	299		0.05
Cooling Water	20	60		0.2

Now let us take a problem and demonstrate this. The process shows in the table below pure countercurrent (1, 1) shell and tube heat exchangers used and delta T minimum is taken to be a 10 degree. Now the problem shows that there are three hot streams and two cold streams, one stream as hot utility, and the other cooling water as cold utility. And the heat transfer coefficients are also given for each stream.

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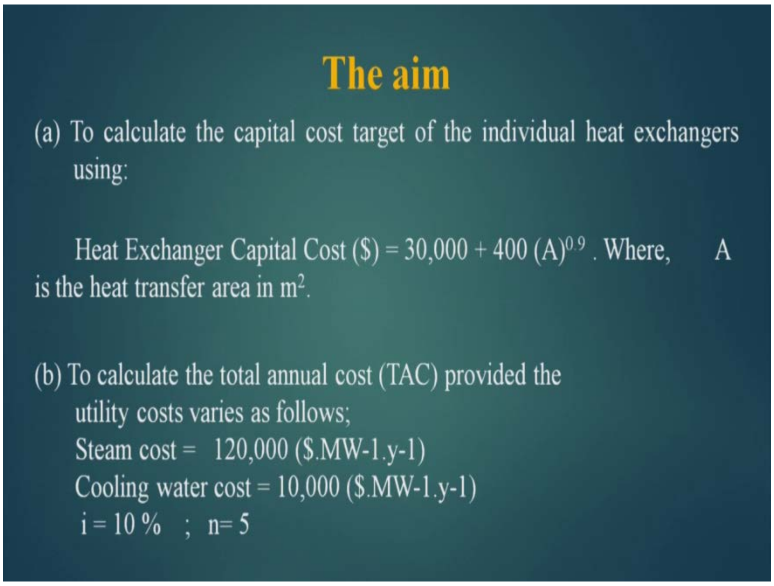

Now the aim of this is to calculate the capital cost target of the individual heat exchangers using the heat exchanger capital cost expression, which is 30000 plus 400 into A to the power 0.9. So, such type of equations will find, where the constant 30400 and 0.9 are this functions of the specification of the heat exchanger, where A is the heat transfer area in meter square. And to calculate the TAC, we should have also the operating cost figures. The utility cost are given below; the stream cost 120000 dollars per mega watt per year, and the cooling water cost 10000 dollars per mega watt per year and i is 10 percent and n is 5 years, and five means the operating life of the heat exchangers, where choosing is five here.

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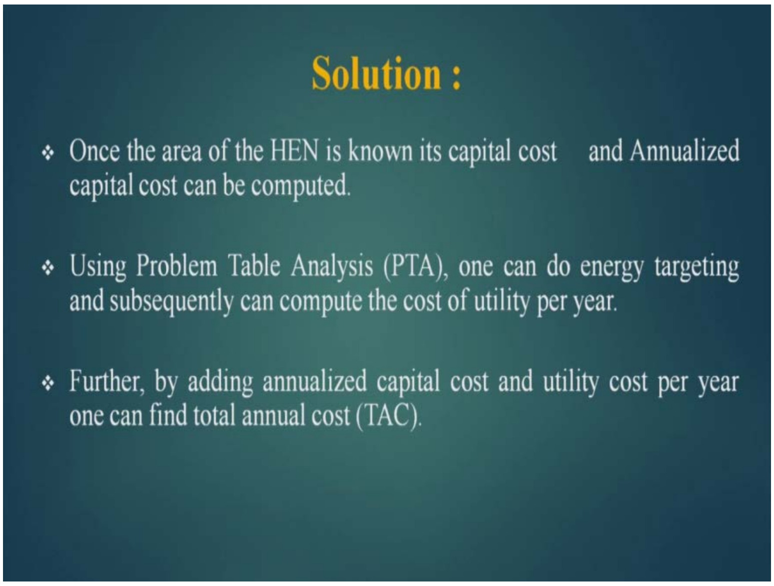

Why if all this data alone, we can do the area targeting. So, the first part will do the area targeting, and based on the area targeting, we will have a area of the heat exchanger network and that area will be use to find out the capital cost of the heat exchanger network. Once the area of hen is known, its capital cost and annualize capital cost can be computed. Using problem table analysis-PTA, one can do energy targeting and subsequently can compute the cost of utility per year. So, utility cost will be known through area targeting the capital cost of the annualize capital cost will be known, once this two part of the cost are known, we can find out the total annual cost-TAC, by adding the annualize capital cost with the utility cost.

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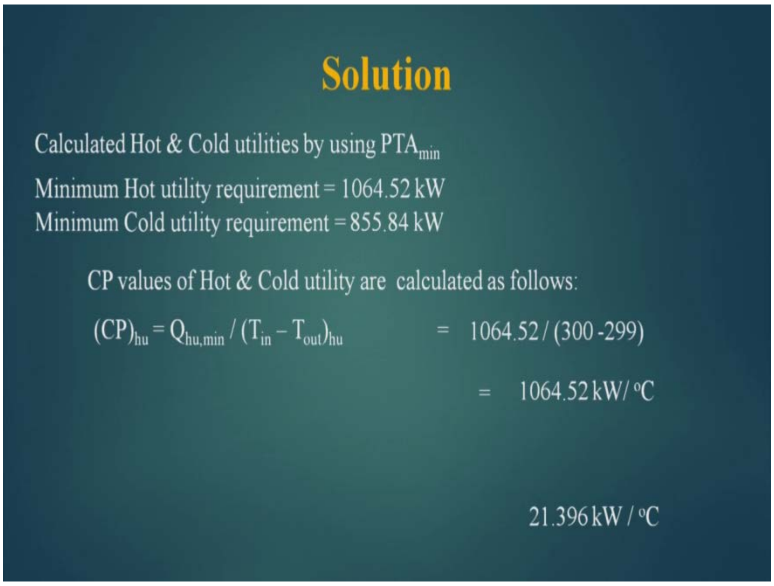

Now if do the PT analysis of the stream table which is given to us then we find that the minimum hot utility requirement is 1064.52 kilowatt; minimum cold utility requirement is 855.84 kilowatt and C p values of hot and cold utilities are calculated as follow. Now for hot utilities, we have calculated this is 1064.52 kilowatt per degree centigrade, and the cold utility is 21.396 kilowatt per degree centigrade. For the hot utility calculation, we will we will see that we have taken the delta T is equal to 1; that means, this stream condenses within a range that is 300 to 299. Why we have taken one degree centigrade, I have already explained in many lectures, and that is why I am not explaining here.

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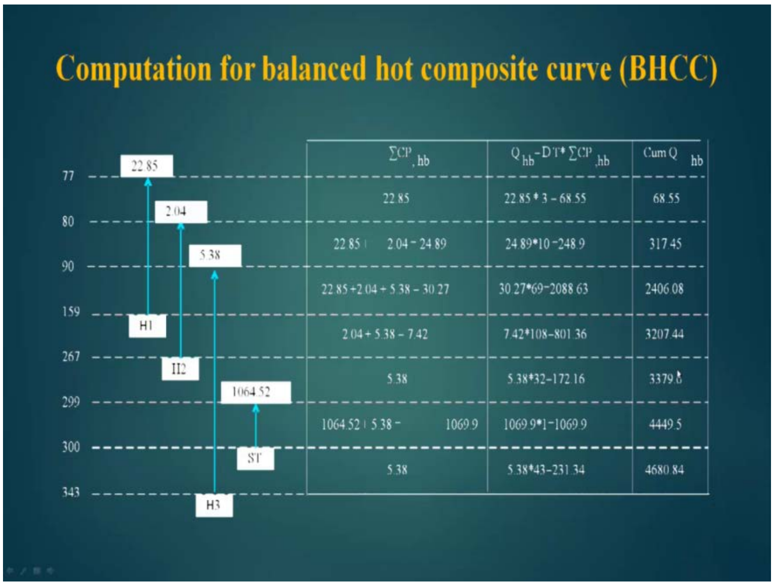

Now what is our aim, our aim is to find out the total heat exchanger area, heat exchanger area of the network. And we know that to do this, we have to plot the balanced hot composite curve and balanced cold composite curve. Because in this area of the heat exchanger network, area of the heaters and coolers are included; and for that, it is necessary that the composite curves should have hot utility and cold utility. So, when we plot the hot utility and cold utility with the composite curve, it converts into a balanced composite curve. So, here we have plotted the streams the H 1 moves from 159 to 77, its C p value is 22.85. H 2 moves from 267 to 80, its C p value is 2.4 and so and so forth.

So, we have taken all the hot streams from the stream table, and we have plotted this. Then we have calculated the summation C p value for the hot streams in the first interval that is 80 to 77 only H 1 stream is operating and its c p value is 22.85. And hence here this is enter 22.85, but happen in the range of temperatures that is 90 to 80, there are two streams H 1 as well like H 2 streams. So, we have added the C p values of both. So, it becomes 22.85 plus 2.04 which comes out to be 24.89. So, in this manner, we have computed these summation of C p values here in this column.

Then we have to calculate the Q hb values, this is calculated as the delta T, which is three degree here from this level to this level into this C p value. So, it comes out to be 68.55 and for this the delta T is 10 and summation of the C p value is 24.89, so 24.89 into 10 is 248.9. So, similarly, all this values are tabulated here, then we calculate the cumulated cumulative q values which is for the first interval this is 68.5, at the second this is 68.55 plus 248.9 which comes out to be 317.45. For similar manner, we have calculated the cumulative values.

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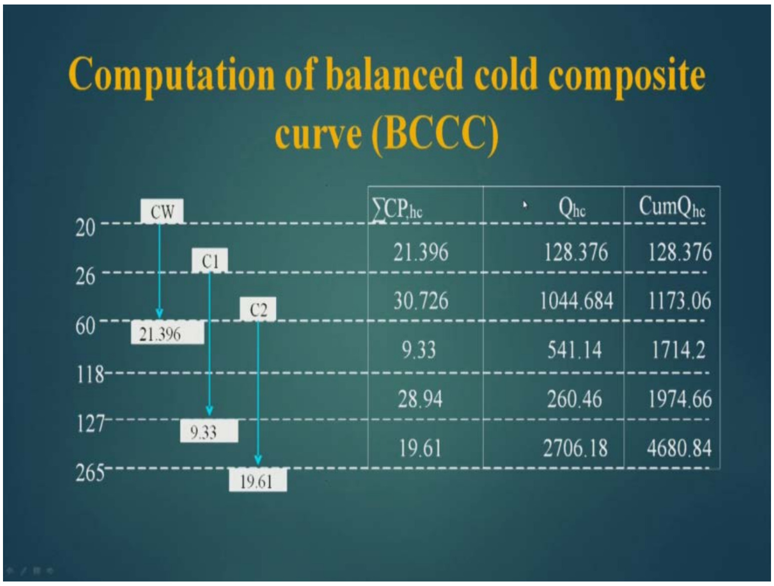

Let us see how to plot the balanced composite curve. For this purpose, we first draw the temperature levels, and then find out the cold streams and the cold utility. Here the cold utilities working from 20 degree centigrade to 60 degree centigrade, the cold stream C 1 is operating from 26 to 127 degrees centigrade, and C 2 is operating from 62 to 65 centigrade. And they have the M C p values for C 2 is 19.61, C 1 is 9.33 and C w that is cold water is 21.396. And then we find out what are the summation of C p values. Now in this temperature range 26 to 20, only cold water is working and its M C p value is 21.396, so here will have 21.396.

Similarly, in this temperature range 60 to 26, two cold streams are working, this cold water and C1, the summation of their C p values is 21.396 plus 9.33, it comes out to be 30.726. So, in this similarly we have filled up this. Now this Q value is computed by multiplying this temperature gap that is 26 to 20 into 21.396 is 128.376. And similarly, we have calculated the Q h values and filled it up. And in the cumulative, so this is and this level it is 128.376; and for this, this is this plus this comes out to be this value 1173.06. Similarly, we have computed the cumulative values.

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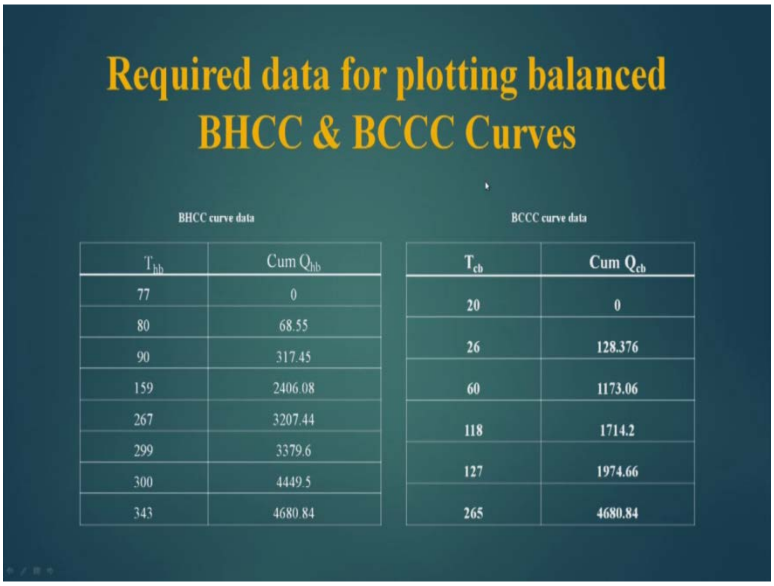

Now we are ready to plot the balanced hot composite curve and balanced cold composite curve which is BCCC, the enthalpy values are different temperatures are known to us this we have already computed for hot balanced composite curve and cold balance composite curve.

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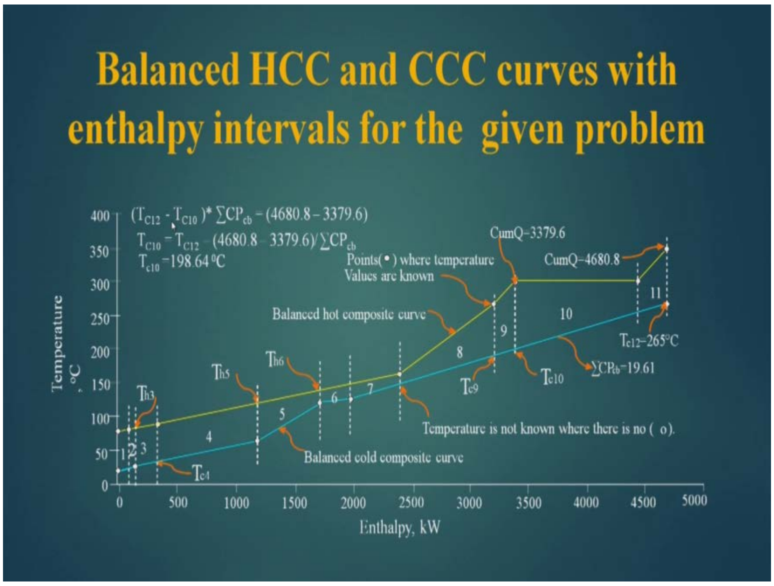

So, based on the cumulative Q values and temperature levels for the balanced cold composite curve, we have first plotted the points and then we have joined them. So, this one show the balanced cold composite curve in which the cold utilities included. Now we can plot the balanced hot composite curve for that will first form plot the points and then will join. So, we have joined this this is balanced hot composite curve, and this is the balance cold composite curve. Now will see that there are places where the temperatures is known for hot balanced hot composite curve, but it is not known for cold composite curve and so and so forth.

Here we see that here this temperature is known for balanced cold composite curve, but the corresponding temperature T h 3 is not known for hot composite curve. Why, this is necessary, because when I segment this balanced cold composite curves into different enthalpy intervals then say I take into account this enthalpy interval to find area, I should know this temperature, this temperature, this temperature and this temperature. In this case, this temperature T c 4 is not known and T h 5 is not known. Unless and otherwise, I find out this two temperatures, I cannot find out the LMTD - log mean temperature difference for this enthalpy interval. So, if it is the LMTD is not known, I cannot find out the area for this interval, enthalpy interval. And to find out the total area of the heat exchanger network, I have to find out the area of each enthalpy interval and then sum them together to find out the area of the total BCC and BSCC and CHCC curve.

So, we will see that how to compute the unknown temperatures. So, example we will take here itself. Now this the equation, I am interested in finding out the T c 10 temperature which is here at this point, T c 10 temperature is there. So, we see that this is a straight line, so we can always apply the straight line interpolation rules or linear interpolations rule which is nothing but this equation for this case. So, here T c 12 minus T c 10 is equal to summation of CP c b - here the 19.61, this summation of this the streams which are present here. Now and then, this is equal to the enthalpy available here, which is this; and the enthalpy available here, which is this. So, if you use this equation, we compute the value of T c 10 as 198.64 degree centigrade.

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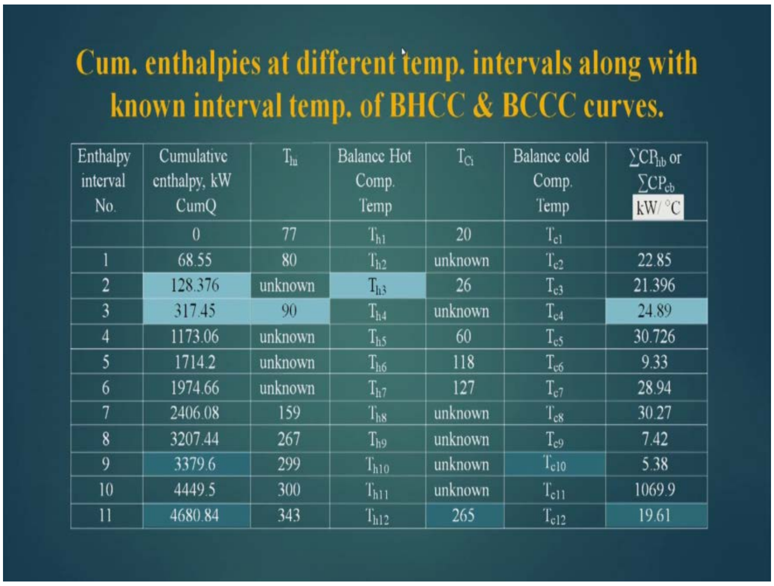

Enthalpy interval No.	Cumulative enthalpy, kW CumQ	T_{hi}	Balance Hot Comp. Temp	T_{Ci}	Balance cold Comp. Temp	$\sum CP_{hb}$ or $\sum CP_{cb}$ kW/°C
	0	77	T_{h1}	20	T_{c1}	
1	68.55	80	T_{h2}	unknown	T_{c2}	22.85
2	128.376	unknown	T_{h3}	26	T_{c3}	21.396
3	317.45	90	T_{h4}	unknown	T_{c4}	24.89
4	1173.06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

Now in the table, if you compute this we find that this T h 3 value is not known, it is using this four values to compute the value of T h 3. Similarly, if you want to find out T c 10, which was shown in the example, it will be using this four values to compute the value of T c 10. So, similarly the all unknown temperatures here in the cold composite curve or in the hot balance composite curve, and we computed and filled up.

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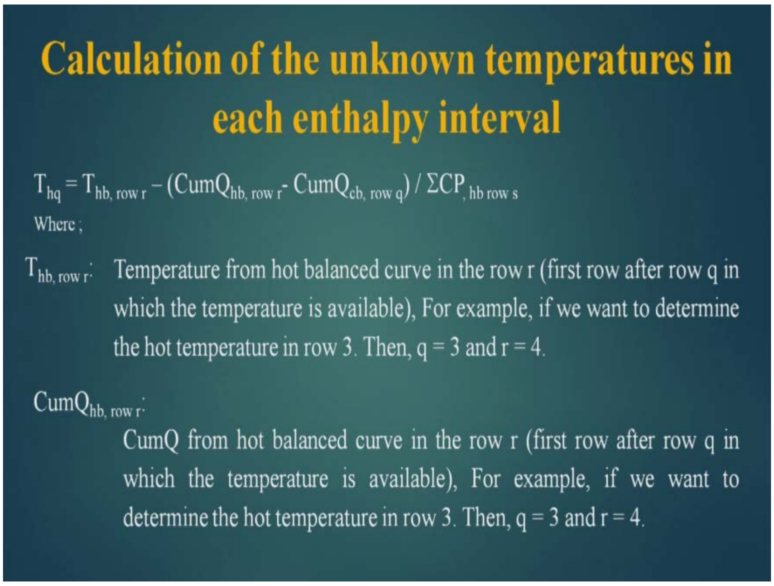

These are the equations given for the computation of…

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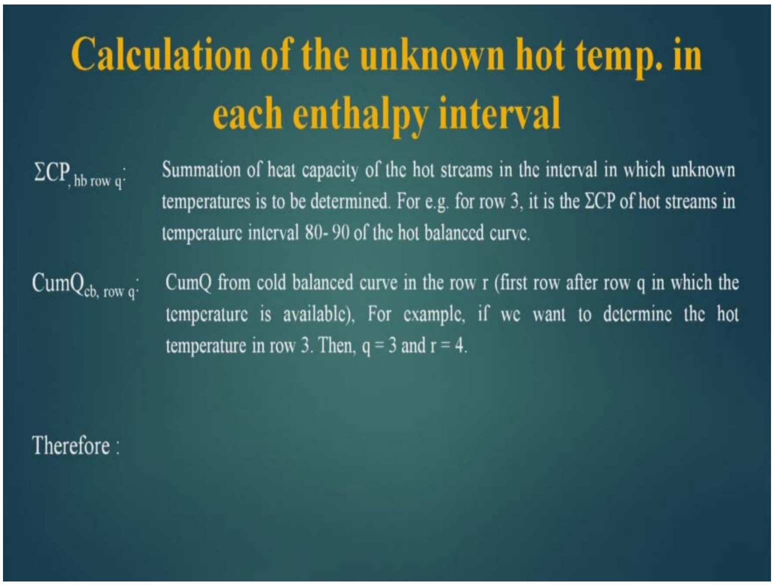

This we have explained clearly. And here it gives you the value of the different unknown temperatures of the balanced hot composite curve, this we have already demonstrated in the area targeting.

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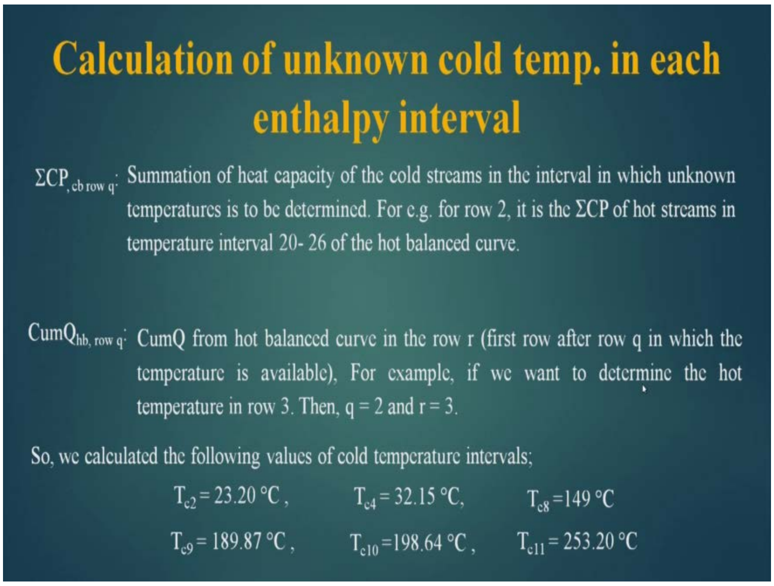

Similarly, we can find out the unknown temperatures of the balanced cold composite curve.

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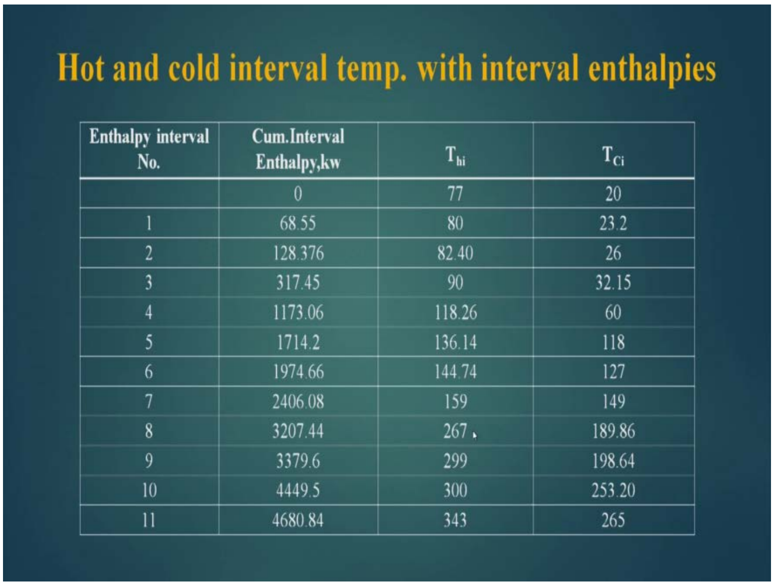

Hot and cold interval temp. with interval enthalpies

Enthalpy interval No.	Cum.Interval Enthalpy,kw	T_{hi}	T_{Ci}
	0	77	20
1	68.55	80	23.2
2	128.376	82.40	26
3	317.45	90	32.15
4	1173.06	118.26	60
5	1714.2	136.14	118
6	1974.66	144.74	127
7	2406.08	159	149
8	3207.44	267	189.86
9	3379.6	299	198.64
10	4449.5	300	253.20
11	4680.84	343	265

Now this shows that we have computed all the temperatures required including the unknown temperatures of the balanced hot composite curve, and all the temperatures required including the unknown temperatures of the cold balanced cold composite curve.

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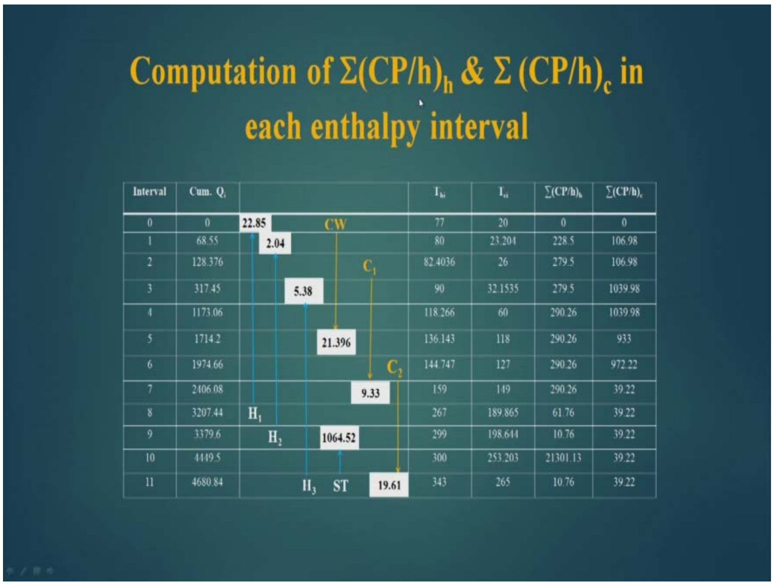

Computation of $\Sigma(CP/h)_h$ & $\Sigma(CP/h)_c$ in each enthalpy interval

Interval	Cum. Q_i		T_{hi}	T_{ci}	$\Sigma(CP/h)_h$	$\Sigma(CP/h)_c$
0	0	22.85 CW	77	20	0	0
1	68.55	2.04	80	23.204	228.5	106.98
2	128.376	C_1	82.4036	26	279.5	106.98
3	317.45	5.38	90	32.1535	279.5	1039.98
4	1173.06		118.266	60	290.26	1039.98
5	1714.2	21.396	136.143	118	290.26	933
6	1974.66	C_2	144.747	127	290.26	972.22
7	2406.08	9.33	159	149	290.26	39.22
8	3207.44	H_1	267	189.865	61.76	39.22
9	3379.6	H_2 1064.52	299	198.644	10.76	39.22
10	4449.5		300	253.203	21301.13	39.22
11	4680.84	H_3 ST 19.61	343	265	10.76	39.22

Now, the most of the data is available to compute the area of the different enthalpy intervals. So, we here compute this CP by h summation CP by h for the hot balanced hot composite curve and CP by h for the balance cold composite curve and this is this we have computed.

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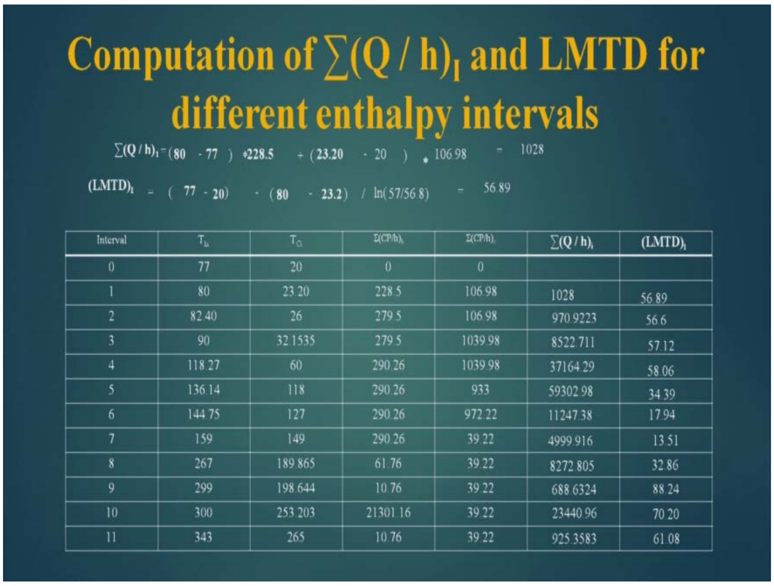

Interval	T_{hi}	T_{ci}	Σ(CP/h)h	Σ(CP/h)c	∑(Q / h)i	(LMTD)i
0	77	20	0	0		
1	80	23.20	228.5	106.98	1028	56.89
2	82.40	26	279.5	106.98	970.9223	56.6
3	90	32.1535	279.5	1039.98	8522.711	57.12
4	118.27	60	290.26	1039.98	37164.29	58.06
5	136.14	118	290.26	933	59302.98	34.39
6	144.75	127	290.26	972.22	11247.38	17.94
7	159	149	290.26	39.22	4999.916	13.51
8	267	189.865	61.76	39.22	8272.805	32.86
9	299	198.644	10.76	39.22	688.6324	88.24
10	300	253.203	21301.16	39.22	23440.96	70.20
11	343	265	10.76	39.22	925.3583	61.08

So, here we compute summation Q by h which is for this first interval. So, this is the temperature difference into the value 228.5 plus 23.20 minus 20, this is taken from here into the this value which is the summation of CP by h. So, it comes out to be 1028. So, this includes the heat available with the hot streams in that temperature interval and the cold streams as well. So, similarly we compute for all other enthalpy intervals, then we can compute the LMTD. So, for LMTD, this temperature, this temperature, this temperature and this temperature will be used. So, we now compute the all LMTD factors.

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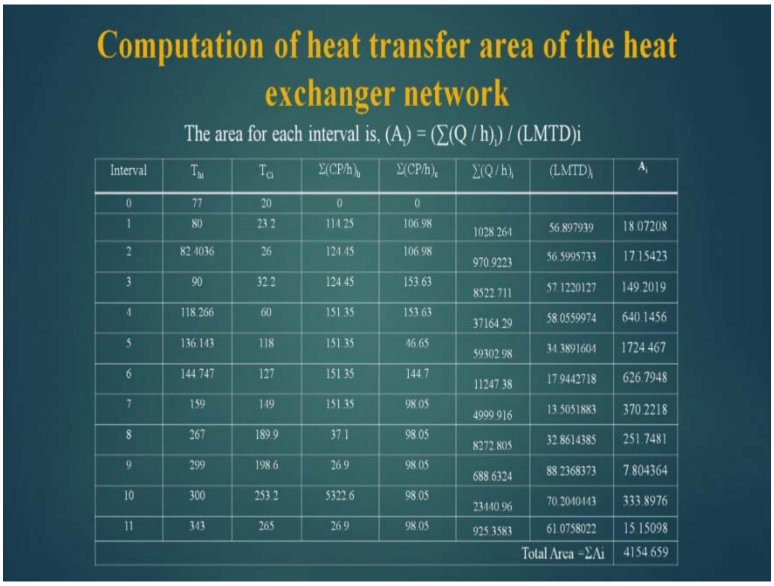

Interval	T_{hi}	T_{Ci}	Σ(CP/h)h	Σ(CP/h)c	∑(Q / h)i	(LMTD)i	A_i
0	77	20	0	0			
1	80	23.2	114.25	106.98	1028.264	56.897939	18.07208
2	82.4036	26	124.45	106.98	970.9223	56.5995733	17.15423
3	90	32.2	124.45	153.63	8522.711	57.1220127	149.2019
4	118.266	60	151.35	153.63	37164.29	58.0559974	640.1456
5	136.143	118	151.35	46.65	59302.98	34.3891604	1724.467
6	144.747	127	151.35	144.7	11247.38	17.9442718	626.7948
7	159	149	151.35	98.05	4999.916	13.5051883	370.2218
8	267	189.9	37.1	98.05	8272.805	32.8614385	251.7481
9	299	198.6	26.9	98.05	688.6324	88.2368373	7.804364
10	300	253.2	5322.6	98.05	23440.96	70.2040443	333.8976
11	343	265	26.9	98.05	925.3583	61.0758022	15.15098
						Total Area =ΣAi	4154.659

Now the area of a temperature interval is given the summation by Q by h value for that interval divided by the LMTD of that interval. So, we have this value known, we have this value known what we have to do is divide this to this and find out the area. So, these are the area values, and when we sum the area it comes to be 4154.659.

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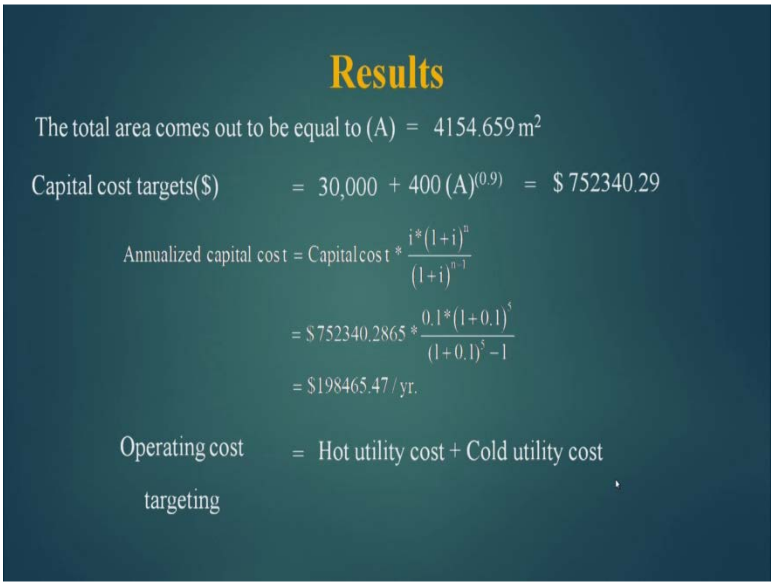

So, we compute the cost of the capital cost based on the area which we have calculated, and then we convert it into the annualized capital cost by multiplying with this factor which comes out to be 198465.47 per year. So, area was this, capital cost we have used this equation for the computation of capital cost. We use capital cost here and then converted multiplied by with this factor to convert it into annualized capital cost. Now the operating cost is hot utility cost plus cold utility cost.

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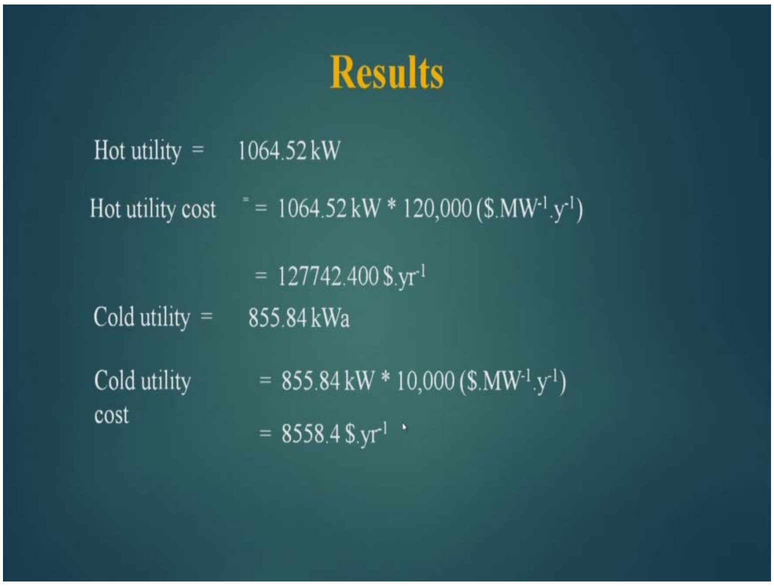

So, this is the amount of hot utility multiplied by the cost of the utility, it comes out to be this. Please remember that this is in megawatt and this is in kilowatt, so obviously, has to be divided by one thousand. Similarly the cost of the cold utility is computed using this. So, this are per years and annualized cost is also per years, so we can add them up. So, total cost of targeting is this plus this. This is the annualized fix capital cost, this is the operating cost. So, the cost is this, total cost which is called TAC.

And then thank you.