Process Integration
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Module - 4
Targeting
Lecture - 4
Problem Table Algorithm - 2nd Part

Welcome to the lecture series on process integration. This is module 4 lecture 4, the topic of the lecture is problem table algorithm second part. In this lecture we will see a new problem table algorithm, which is used to find out the hot and cold utilities. Based on the conventional problem algorithm, one can determined hot and cold pinch temperatures and can also target hot and cold utility demands.

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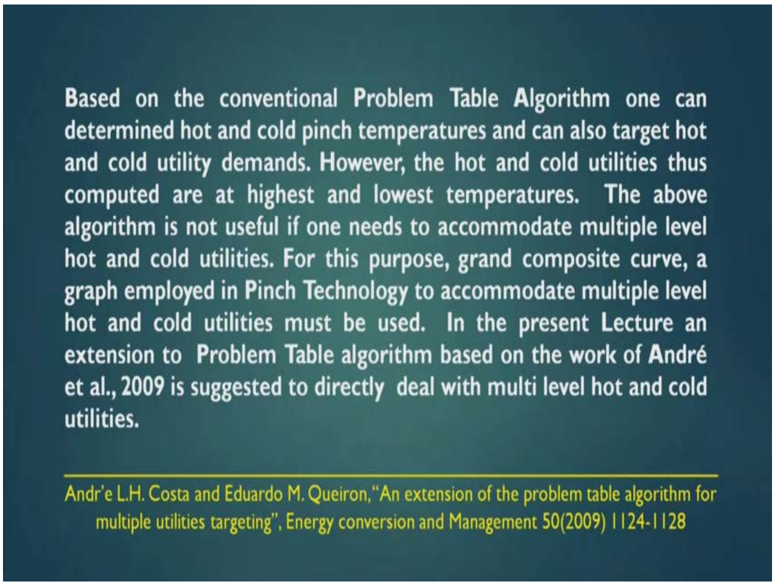

However, the hot and cold utilities thus computed are at highest and lowest temperatures. The above algorithm is not useful, if one needs to accommodate multiple level hot and cold utilities. For this purpose, grand composite curve, a graphical method is employed in pinch technology, to accommodate multiple level hot and cold utilities. In this present lecture, an extension to the problem table algorithm based on the work of Andre et al 2009 is suggested to directly deal with multi level hot and cold utilities. To demonstrate this algorithm, that is extension to the problem table algorithm, a four stream problem.

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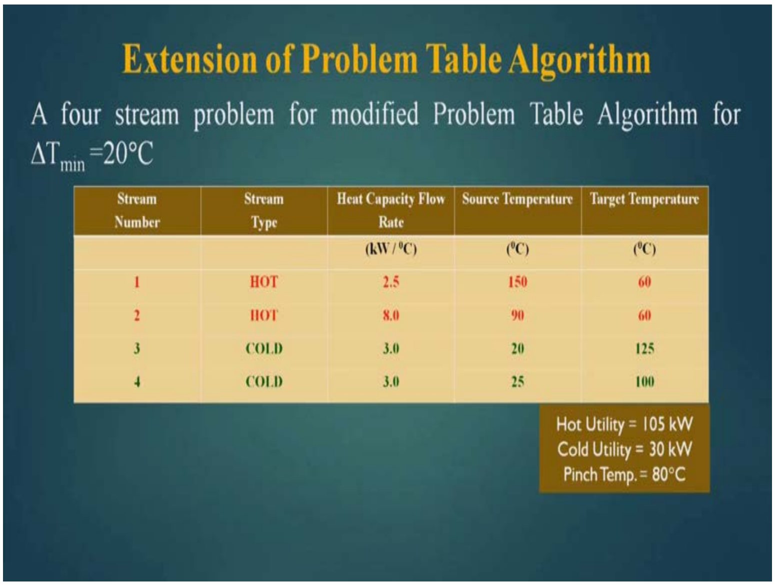

For modified problem table algorithm, for delta T minimum equal to 20 degrees centigrade taken; there are two hot streams, and two cold streams, source temperature and target temperatures are given and incapacity flow rate are given. If you do the PTA analysis of this stream table, then we find that hot utility requirement is 105 kilowatt, cold utility demand is 30 kilowatt and pinch temperature is at 80 degree centigrade

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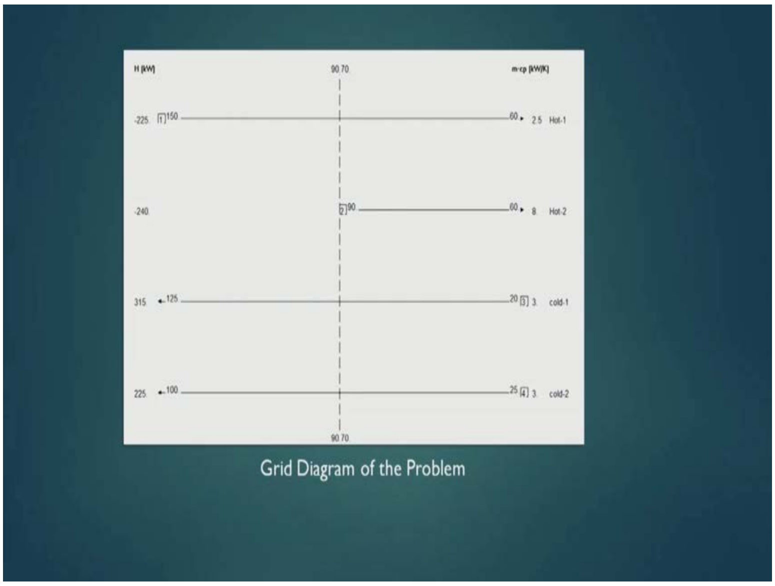

Now, this is the great diagram of the problem. You see that there are three streams, in the above pinch area and four streams in the below pinch area.

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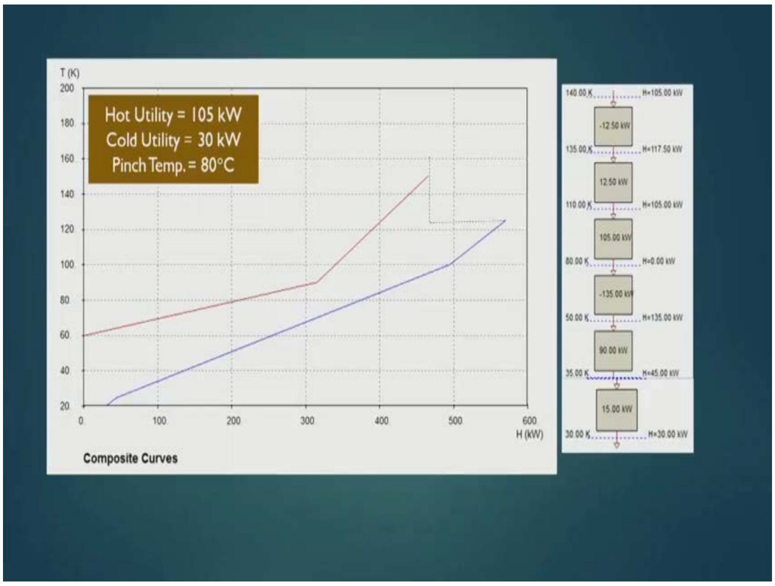

This is the composite curve, it very clearly shows that multiple hot utilities can be used, you can use a hot utility here, if you want you can use a hot utility here, you can use a hot utility here. So, you can use a hot utility here, based on the delta T minimum criteria and this is the cascading. And these are the temperature levels and it shows the amount of it cascading down. Let us see some nomenclature is being used, for the present algorithm, in this procedure the number of utilities and their temperature ranges must be noted at the beginning of the procedure.

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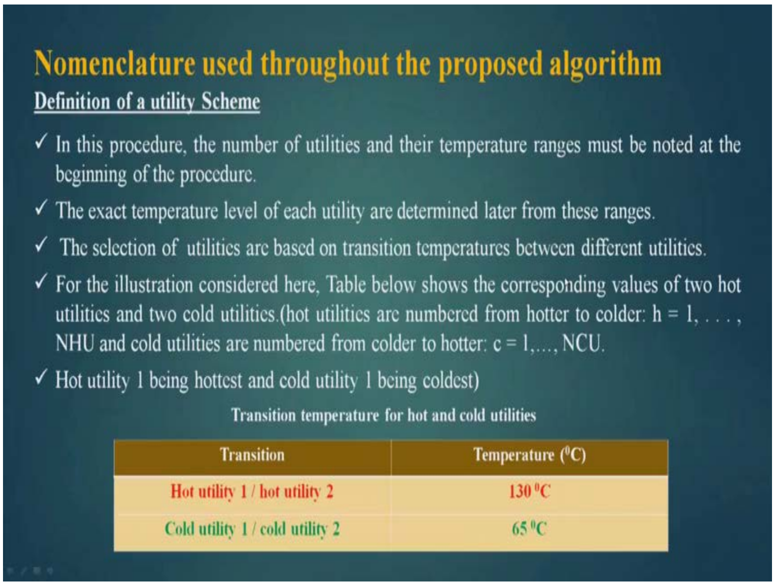

The exact temperature level of each utility are determined later, from the algorithm from these ranges, the selection of utilities are based on transition temperature between different utilities. This is very important line in which, we will keep different utilities based on that transition temperature, this will be clear. For the illustration considered here, table below shows the corresponding values of two hot utilities and two cold utilities. Hot utilities are numbered from hotter to colder, this is very important, that means I say hot utility numbered 1 then it will be hotter than the hot utility numbered 2. And hot utility numbered 2 will be hotter than hot utility numbered 3.

So, hot utilities are from 1 to NHU and cold utilities are from 1 to NCU number and cold utility numbered 1 will be cooler than, cold utility numbered 2. And cold utility numbered 2 will be cooler than, the cold utility numbered 3. So, hot utility 1 being hottest and cold utility 1 being coldest in this range. So, for this problem we are taking two hot utilities and two cold utilities. Hot utility numbered 1, hot utility numbered 2 and that transition temperature is 130, that means 130 and above, we are using hot utility numbered 1 and 130 below we are using hot utility numbered 2.

Cold utility numbered 1 and cold utility numbered 2, that means two cold utilities we are using. So, the cold utility numbered 1 is below 65 and cold utility numbered 2 is equal to 65 or above 65. So, in this algorithm the transition temperature of hot utilities and cold utilities are given. Now, if you analyze what is the range of hot utility or the bounds of the hot utility then we will see that maximum bound of the hot utility is this.

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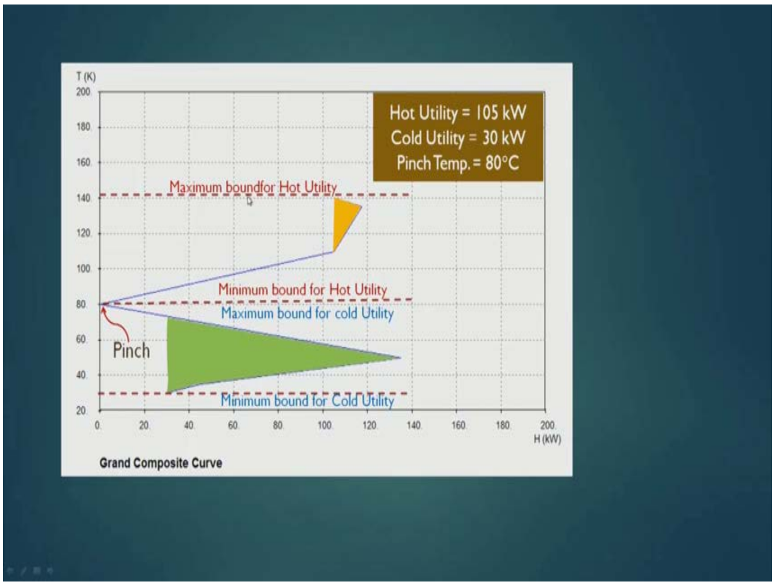

And the minimum bound of the hot utility is pinch temperature. So, the all hot utilities will raise from here to here, whether I am using two hot utilities or two cold utilities or three hot utilities or four hot utilities. So, the maximum bound will be within this two lines similarly, the minimum bound, for the cold utility will be this. And the maximum bound for the cold utility will be pinch temperature level. So, all the cold utilities will fall within this range.

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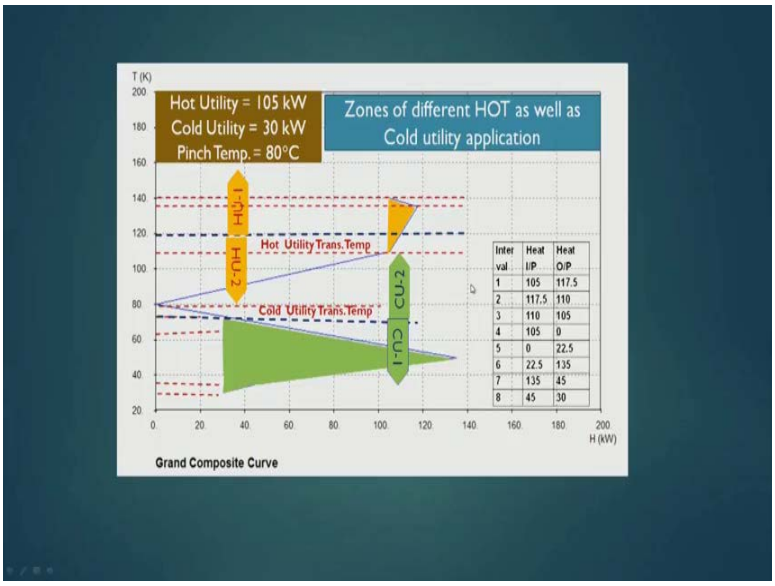

Now, here in this diagram which is a grand composite curve and this is shifted temperature verses, delta h. Here we have put the transition temperature of hot utilities. So, this line is the transition temperature of the hot utilities, above this is hot utility, 1 is used and below the hot utility 2 is used. Similarly, the cold utility transition temperature is given by this line so cold utility 2 is used above it. And cold utility 1 is used below this and these are the different temperature levels of the system.

So, between this and this temperature, this is interval 1, this is interval 2, this is interval 3, this is interval 4, this is interval 5, interval 6, this is 7 and this is 8. So, there are 8 intervals and these are the heat input and output to a interval. So, to the first interval heat input is 105 and heat output from this interval is 117.5. So, for these values, this interval values these are the heat input and heat output. And in this algorithm, we are calculate this value and based on these values, all decisions will be taken. In this approach, the transition temperature between utilities are added to the set of source and target temperatures and the problem table algorithm is then applied.

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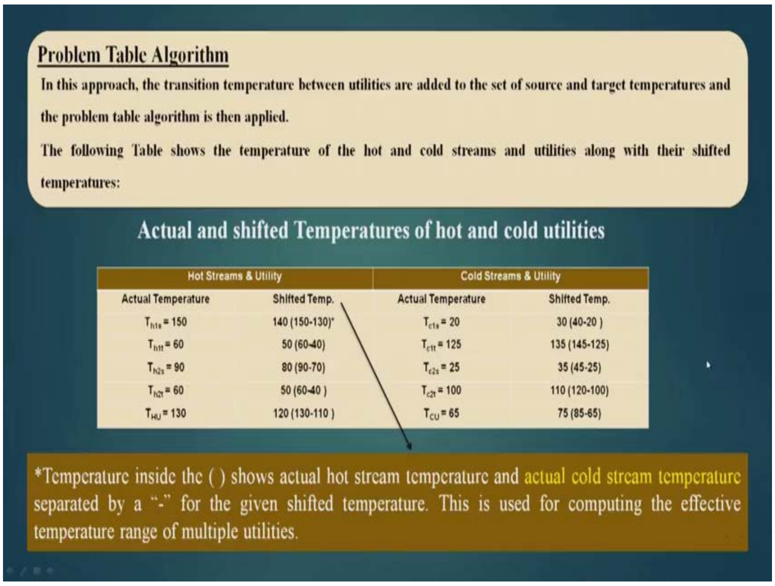

This is very important factor that, what we have done the transition temperatures of the utilities, that means hot utilities as well as cold utilities are added to the source. And target temperatures of different streams, and the problem table algorithm is then applied. So, now the transition temperatures are an integral part of the problem table algorithm.

Let us see this, the actual and shifted temperatures of hot and cold utilities, we know that delta T minimum is 20 degree.

So, here if you take the actual temperature of the hot stream, the highest temperature is 150 degree then 60 degree then 90 degree then 60 degree and this THU is transition temperature between the two hot utilities hot 1 and hot 2. And if you find out the shifted temperature of this, the delta T minimum is 20 degree centigrade. So, we deduct 10 degree centigrade to this because the shifted temperatures are actual temperatures minus delta T minimum by 2. And delta T minimum by 2 in these cases is 10 so 150 minus 10 is 140 degree.

Now for this 140 degree centigrade, if I compute this actual temperature of the hot and cold. So, if it is a hot shifted temperature I have to add 10 degree that becomes, 150 and if this is a cold shifted temperature then I have to deduct 10 degree from this 140 so it becomes 130. So, my range is 150 to 130 that means, if it is a hot temperature it is a 150 actual temperature and if it is a cold, 130. So, two actual temperatures of hot and cold are written for this shifted temperatures here. Similarly, you have 60 so I will deduct 10 so it becomes 50 so for hot it is 60 and for cold it is 40.

Similarly, this is 90 I deducted 10 this is 80, 90 to 70. So, I write down these temperatures like this and for this THU, what is the transition temperature of hot utility 1 to 2, I also write the same thing. Then for cold streams I repeat this. This is 20, 125, 25, 100 and this is the transition temperature of cold 1 to cold 2, which is 65 degree centigrade in this case. So, here we will add 10 degree to this to converted into the shifted temperature, so this is 30.

For this 30 shifted temperature, if I converted into a hot temperature then it will becomes 40 and for cold temperature it become, hot temperature it will be added 10 so 40 and cold temperature it is 20. Similarly, hot and cold temperature for all temperature levels, that is shifted temperature levels, we have computed. This thing, that is marks as asterisk mark, the temperature inside this bracket shows the actual hot stream temperature and actual cold stream temperature, separated by a dash for the given shifted temperature. This is used for computing, the effective temperature range of multiple utilities, why we have done, so because we have we want to calculate the actual temperatures of the multiple utilities. That means, actual temperature range of the multiple utilities and that is why we have preserved this data and with the temperature levels.

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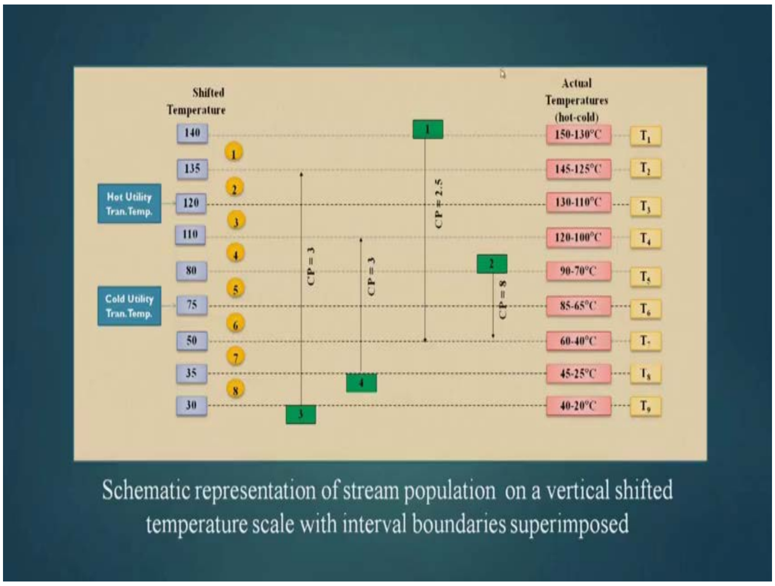

Now, here all temperature levels, shifted temperatures levels have been written. That is all shifted temperature levels of the hot as well as all the shifted temperature levels of the cold and these are the temperature intervals 1 to 8. These are the actual temperature range, that is hot to, cold for this shifted temperature intervals. Similarly, for the all shifted intervals, I have written the hot to cold temperatures. And this we named T1, T2, T3, T4 to T9 these temperatures.

Then, if you see the range of streams that, the streams are working numbered 1 stream is working from this shifted temperature level to this shifted temperature level. The CP value is 2.5, 2 is working from this shifted temperature level to this shifted temperature level CP is 8. The 3 is working from, this temperature level to this temperature level and this CP is 3 and 4 is working from this temperature level to this CP is 3. Now, we will used this information for making others tables so here the shifted temperature levels.

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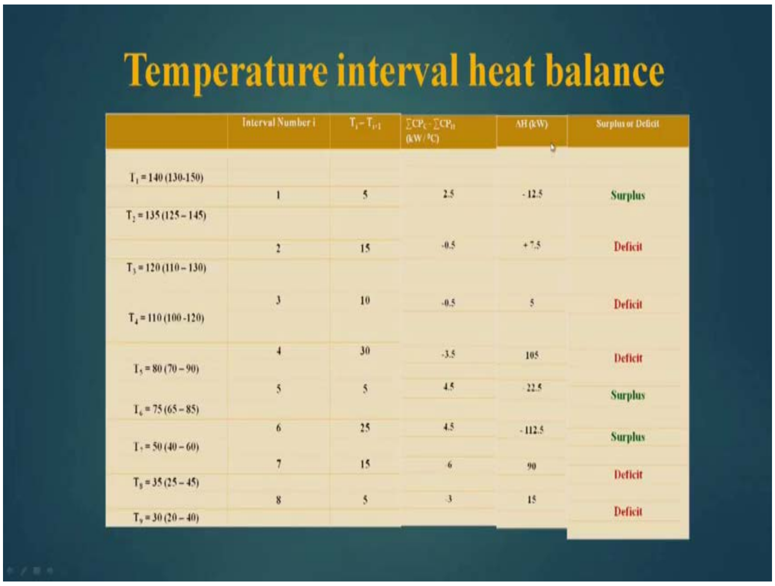

These are the temperature intervals and this is delta T, T i minus T i minus T i plus 1. So, here 14- and 135 difference is 5 here, 135, 120 difference is 15. So, we have written the difference of two temperature levels in interval then summation CPC minus CPH value. So, based on the stream available T of stream at different temperature levels, which has been shown you in the last slide. We have computed these values, 2.5, minus 0.5, minus 0.5, minus 3.5, 4.5, 4.5, minus 6 and 3. Then we have multiplied this with this, that is delta T with the summation CPC minus summation CPH values and this is computed. This is minus 12.5, this is minus 7.5, this is 5.

This is 105, this is minus 22.5, this is 112.5, 90 and 15. Now, a negative quantity shows the surplus that means, in this temperature interval heat is available, surplus. And this temperature level, which is below this two numbered, it is deficit because we have a positive sign here. So negative sign shows surplus and positive sign shows deficit. So, this is a deficit temperature interval, this is also a deficit temperature interval, this is also a deficit temperature interval, this is a surplus interval, this is a surplus interval, this is a deficit interval, this is a deficit interval. So, we also know the heat will flow from higher temperature to lower temperature naturally. So, the heat available here can be given to this to compensate this deficit, but heat from here to here, it cannot go. But when deficit is more then heat has to come from top that means, from the hot utility.

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Intermediate computations

	ΔH (kW)	Cascaded Heat kW	Adding heat equal to max. –ve value(-105)	Input/output selection
T_1 = 140 (130-150)		0 (heat input to interval 1)	105(heat input to interval 1)	Heat Input to interval(i)= 1
Interval =1	- 12.5	0-(-12.5) = 12.5	117.5	Heat Output from i=1 and input to i=2
T_2 = 135 (125 – 145)				
Interval =2	+ 7.5	12.5-7.5 = 5	110.0	Heat Output from i=2 and input to i=3
T_3 = 120 (110 – 130)				
Interval =3	5	5-5=0	105	Heat Output from i=3 and input to i=4
T_4 = 110 (100 -120)				
Interval =4	105	0-105 = -105	0	Heat Output from i=4and input to i=5
T_5 = 80 (70 – 90)				
Interval =5	- 22.5	-105-(-22.5)=-82.5	22.5	Heat Output from i=5and input to i=6
T_6 = 75 (65 – 85)				
Interval =6	- 112.5	-82.5-(-112.5)=30.0	135	Heat Output from i=6 and input to i=7
T_7 = 50 (40 – 60)				
Interval =7	90	30.0-90=-60	45	Heat Output from i=7and input to i=8
T_8 = 35 (25 – 45)				
Interval =8	15	-60-15=-75	30	Heat Output from i=8 and input to none
T_9 = 30 (20 – 40)				

So, let us see that now suppose, 0 heat is coming from outside to this temperature interval. So, the heat requirement is 0 minus, minus 12.5, this is 12.5, heat requirement here is 5 heat required is 0 here, heat requirement is here minus 105, 82.5, 30, 60 and 75. So, maximum negative quantity is 105 and this is requirement at this temperature level. Now, even so to make it 0 what we have to do, we have to added the heat from the top. So, if you added 105 heat input this interval then we see that in this interval this is 117.5, this is 110. This is 105 and that becomes 0, this is 22.5, this is 135, this is 45 and this is 30. So, this is the heat flow in different temperature intervals and we see that, all these values are positive in nature. And that is why this is the feasible table, that means if it works like this, the system will work or hen will work.

Now, in this algorithm which is little bit different than the earlier PTA algorithm, the heat input to the different levels and heat output from different levels, are recorded simultaneously. And these two values or columns which will be generated now, will be used for the computation of the requirement of different hot utilities. As well the requirement of different cold utilities, plus these information’s will be used to compute the temperature range of hot utility 1, temperature range of cold utility 1 and temperature range of cold utility 2 and hot utility 2.

So, here let us try to understand, to this temperature, this interval, the input is 105 and 170 is the heat output from interval, i equal to 1, but it is input i equal to 2. Similarly, 110 is heat output from, i equal to 2 and heat input to, i equal to 3 so 105 is heat output i equal to 2 and heat input to 4. And this is 0, is heat output from i equal to 4 and input to i equal to 5 so this 0 shows this is the pinch, heat out from this 22.5 shows heat output from, i equal to 5 and input to i equal to 6. Similarly, we can write down for 135, 45 and 30, which is heat output from i equal to 8 and heat input to none. So, this is our cold utility requirement total cold utility requirement.

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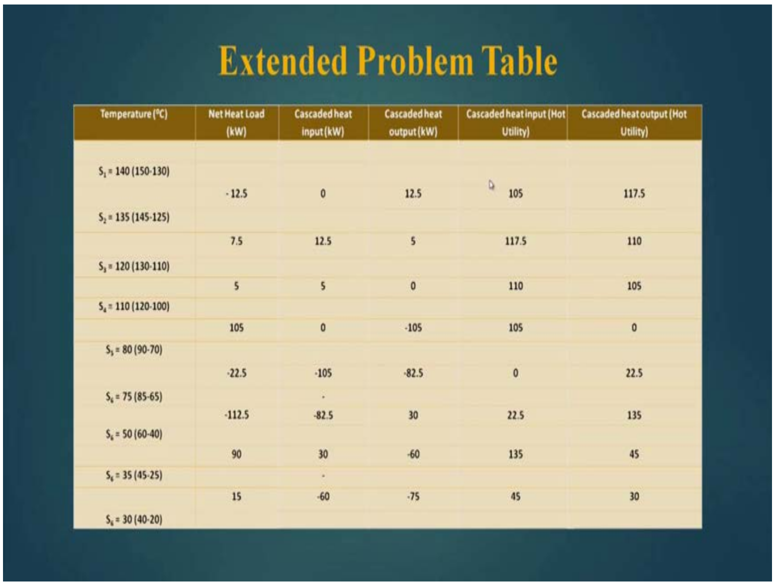

Temperature (°C)	Net Heat Load (kW)	Cascaded heat input (kW)	Cascaded heat output (kW)	Cascaded heat input (Hot Utility)	Cascaded heat output (Hot Utility)
S_1 = 140 (150-130)					
	- 12.5	0	12.5	105	117.5
S_2 = 135 (145-125)					
	7.5	12.5	5	117.5	110
S_3 = 120 (130-110)					
	5	5	0	110	105
S_4 = 110 (120-100)					
	105	0	-105	105	0
S_5 = 80 (90-70)					
	-22.5	-105	-82.5	0	22.5
S_6 = 75 (85-65)					
	-112.5	-82.5	30	22.5	135
S_7 = 50 (60-40)					
	90	30	-60	135	45
S_8 = 35 (45-25)					
	15	-60	-75	45	30
S_9 = 30 (40-20)					

And this is our total hot utility requirement. Now this shows the cascaded heat input to different intervals and this shows the cascaded heat output to, from different intervals. So, heat output to interval, heat input to interval 2 is 117 and heat output from interval 1 is 117.5. This is input to second interval so we have similar values here because one is input and other is output. This shows our cold utility requirement, that is 30 and this shows our hot utility requirement which is 105.

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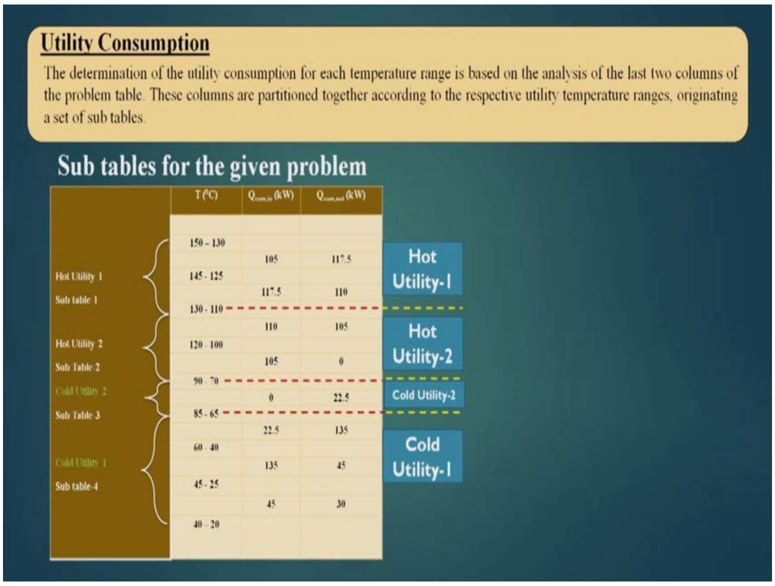

Now based on the last two columns, this is cumulative q in and this is q out, cumulative q in and cumulative q out. And these are the temperatures, that is hot and cold temperatures of a temperature level. Now, we divided this into sub tables. Now, this is the transition temperature on 130 so above this hot utility 1 is used. So, this is the table, these values are in this table, which we called sub table 1 and this is for hot utility 1, this is hot utility 1, sub table 1. So, these are the data which are available here similarly, here up to this, this is the pinch temperature up to this, the hot utility 2 works in this region.

So, this is hot utility 2, sub table 2 so from this temperature level to this temperature level, its data is this, this will be used for computation of hot utilities and cold utilities for different temperature levels. This is for cold utility 2 and similarly, this is for cold utility 1 so this is table numbered 3 and this is cold utility 1, table numbered 4 and you see that this is cold utility 1, this is cold utility 2 because cold utility 1 will be the coolest one.

So, it will be in lower temperature than cold utility numbered 2, but here this is a reveres2. Hot utility 1 will be the highest temperature and hot utility 2 will be as a lower temperature. So, computation for hot utility will, from this direction and computation for cold utility, it will be from the bottom side. So, this shows cold utility 1 range, this is cold utility 2, this is hot utility 2 and hot utility 1.

Now, this have been divided into sub tables 1, 2, 3 and 4 and then operation should take place in this sub tables, if I am interested in computing the amount of hot utility 1 so I will work with this sub table. If I am interested in hot utility numbered 2, will work with this table, if a cold utility 2, will work in this table and cold utility 1, will work on this table. So, these three columns will be used for calculating, the amount of hot utility 1, hot utility 2, cold utility 1 and cold utility 2 and also, the temperature ranges of the hot utilities and cold utilities. This we are going to see. Now, let see the algorithm, how to compute the amount of hot utilities for each hot utility sub table.

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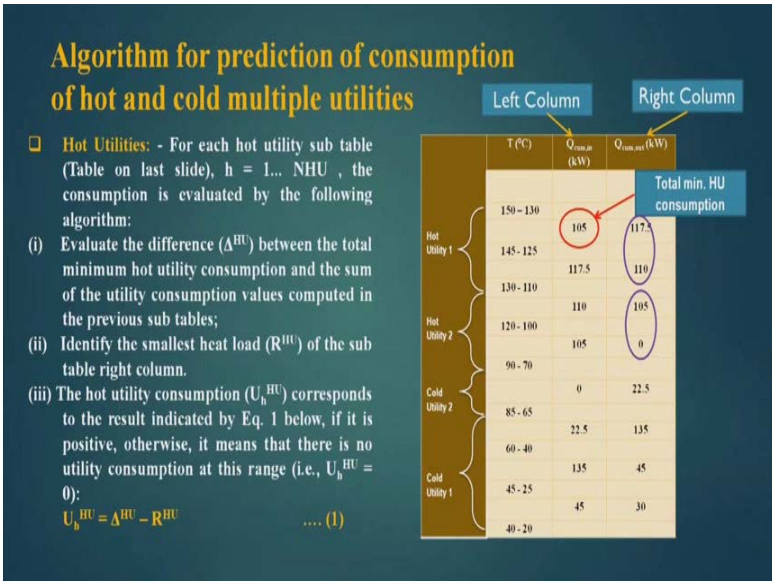

h 1 to NHU, the consumption is evaluated by the following algorithm. So, first job will be to compute hot utility 1 so this is the table, we will be using table numbered 1 for the hot utility. Evaluate the difference delta HU between the total minimum hot utility consumption and the sum of the utility consumption values, computed in the previous sub tables. For hot utility numbered 1, the total minimum hot utilities 105, this is the total minimum hot utility consumption. And consumption above this is 0 because that is no table above this hot utility 1.

So, its consumption is 0, then identify the smallest heat load RHU of the sub table right column. So, for hot utility computation will go for this right column and for cold utility consumption, will go for this left column. So, in this table the right column is this and that are two entries in the right column 117.5 and 110. So, we have to calculate the identify this smallest heat load of this table right column. So, this is 117.5 and 110 so obviously smallest load will be 110. The hot utility consumption Uh HU, correspond to result indicated by equation 1 below. So, this is the equation will be using to compute the amount of hot utility 1 and 2.

Now, below this if it is positive otherwise, it means that there is no utility consumption at this range. That means if the values of Uh HU comes out to be negative, we will take it to be 0. And if it is positive then it has got a minimum and it will show the hot utility consumption. Similarly, when we go for the table 2, that means hot utility 2, we will take these two values to compute. Now, let us see the cold utility now for the cold utilities.

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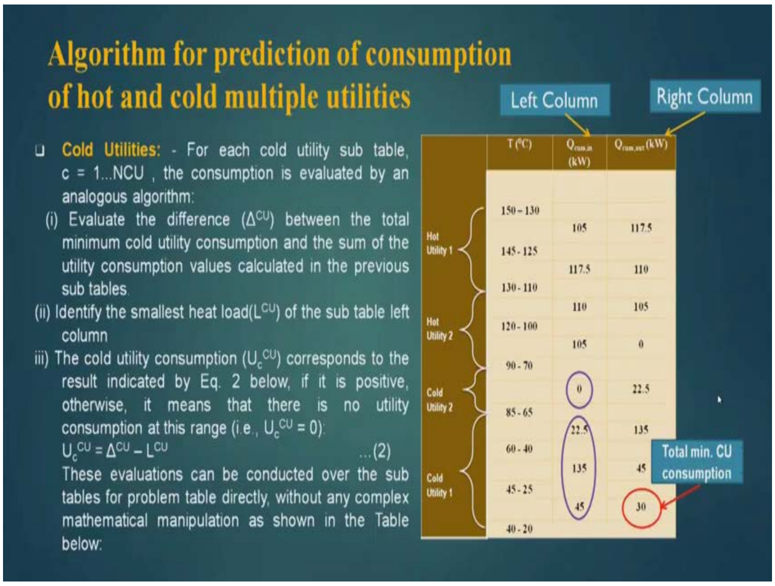

For each utilities sub table c 1 to NCU will be using, now the cold utility 1 is this area. So, there are three entries in the left column of this sub table and we will used this. And this 30 shows the, total minimum CU consumption, that is cold utility consumption. Evaluate the difference, delta CU between the total minimum cold consumption and sum of the utility consumption values calculated in the previous sub tables. Now, there is no previous table below this cold utility 1 so the total minimum consumption is 30 minus 0 because there is no sub table here, below this.

Then, identify the smallest heat load LCU of the sub table left column so in the left column these are three entries in the sub table. So, I have to calculate the minimum of these three then the cold utility consumption Uc CU corresponds to the result indicated by equation 2. This is result I will be using and here also, that if it is positive then otherwise, if it is negative then it will be taken as 0.

These evaluations can be conducted over the sub table for problem table directly, without any complex mathematical manipulation, as we will see now. So, when we calculate a hot utility or cold utility will remain in its table so data of this table will be used. Let us go to the computation so we go for the hot utility 1. So, here it shows the tables, this is table 1 so this four values are there. This shows the marking so we will compute the hot utility from here will compute and cold utility from this direction. So, hot utility estimation, now hot utility numbered 1.

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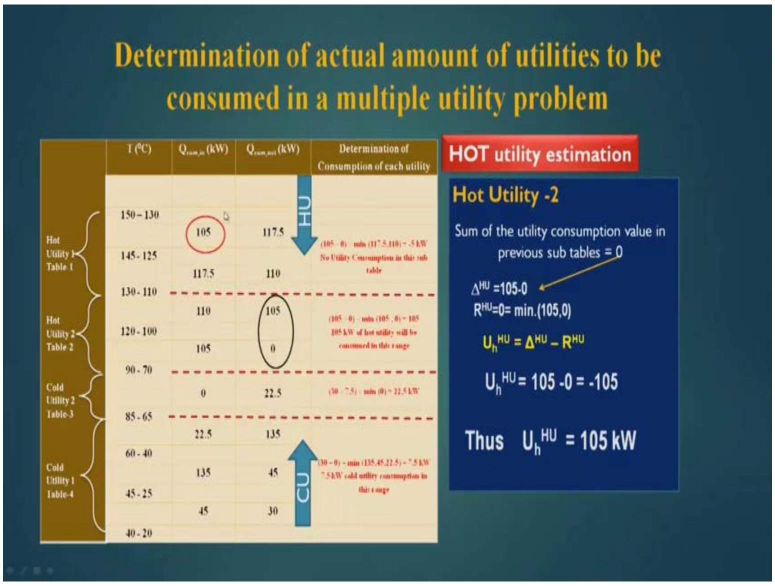

Sum of the utility consumption value in previous sub table is 0 because there is no previous sub table. So, energy consumption or hot utility consumption in previous table is taken to be 0. So, delta HU is calculated by this 105, this is hot utility requirement minus the hot utility consumptions value in the previous table which is 0. So, this is 105 minus 0, the RHU value is minimum of these two. So, 117.5 and 110, the minimum is 110.

So Uh HU can be calculated from this equation, it becomes 105 minus 110 which is minus 5. As we have already told that if Uh HU value is negative then it will be taken as 0 and if it is positive then only we take the value of the hot utility. So, as the value of Uh HU is negative, it is taken to be 0, so Uh HU is 0. So, you can conclude here that, the hot utility demand or hot utility 1 demand for this problem is 0. Now, we go for the hot utility numbered 2, how to compute this.

Now, sum of the utility consumptions value in previous sub table is 0 because we know that the hot utility requirement of utility, hot utility 1 is 0. And above the hot utility on1e also, requirement is 0 so sum of the utility consumption values in the previous sub table is 0. So, this is very clear now, delta HU will be the hot utility requirement minus the sum of the utility consumption values in the previous sub table, which is 0. So, here also it is 105 minus 0, well this 105 comes from here, it is hot utility requirement.

So, delta HU is 105 minus 0, RHU will be calculated from this table, this is utility numbered 2 table. So, minimum of 105 and 0 so this is minimum of 15 and 0 is 0. So, delta HU value is 105, RHU value is 0. So, I can put it here Uh HU equal to 105 minus 0 and this comes out to be 105, this is not negative this is 105.

So, Uh HU is 105 kilowatt this is 105 minus 0, is 105 here, it is not negative so this is 105 kilowatt. So, my hot utility consumption of the utility numbered 2 is 105, if I see the hot utility requirement is 1 is 0, hot utility requirement 2 is 105 and if you remember that the hot utility requirement of the total problem is, 105 also. That is, hot utility numbered 1 plus hot utility numbered 2 is 105, which is the requirement of total hot utility for this problem.

Now, cold utility estimation now, from here in this direction will estimate the cold utility because cold utility numbered 1 is the coolest cold utility. So, here if you see the sum of the utility consumption value, in the previous sub table it is 0. Because, there is no cold utility requirement below this table so it is taken to be 0. Now, cold utility requirement is 30 so delta c u is 30 minus 0 is comes from here.

Now, for cold utility will go for this, this left hand side column or hot utility will go using this, but cold utility for LCU, will go for this computation. So, LCU is minimum of these three quantities so minimum of 135, 45 and 22.5, this comes out to be 22.5. So, now delta CU is known to us and LCU is known to us, so Uc CU is delta CU minus LCU is, 30 minus 22.5, this is 7.5. So, the cold utility consumption, for utility numbered, cold utility numbered 1 is 7.5 kilowatt, this is a positive value.

So, we accept this so this is 7.5 now, let us go to the cold utility numbered 2. So, sum of the utility consumption values in the previous sub table is 7.5 because the cold utility requirement was 7.5. Hence sum of the utility consumption values in previous sub table is 7.5 and below this was 0. So, obviously this is 7.5, so delta CU will be 30, which is the cold utility requirement minus the sum of the utility consumption values in previous sub table, which is 7.5, it comes 7.5 here. So, when I deducted 7.5 from 30, it is 22.5 kilowatt.

Now LCU is 0, as this is only one entry here and minimum of 0 is 0. So, Uc CU for the utility numbered 2 is delta CU minus LCU, this is 22.5 minus 0, is equal to 22.5. So, the cold utility demand for the utility numbered 2 is 22.5 now, if I add these two values that means cold utility demand 1 and cold utility demand 2 then this is 22, 5 plus 7.5 which is 30 kilowatt.

And we know that, for this problem the cold, the total cold utility demand is 30 kilowatt. Once we have computed, the hot utility 1 demand, hot utility 2 demand, cold utility 1 demand and cold utility 2 demand then we will try to compute the temperature ranges of these utilities. Now, you see the algorithm for the determination of the feasible utility temperature ranges.

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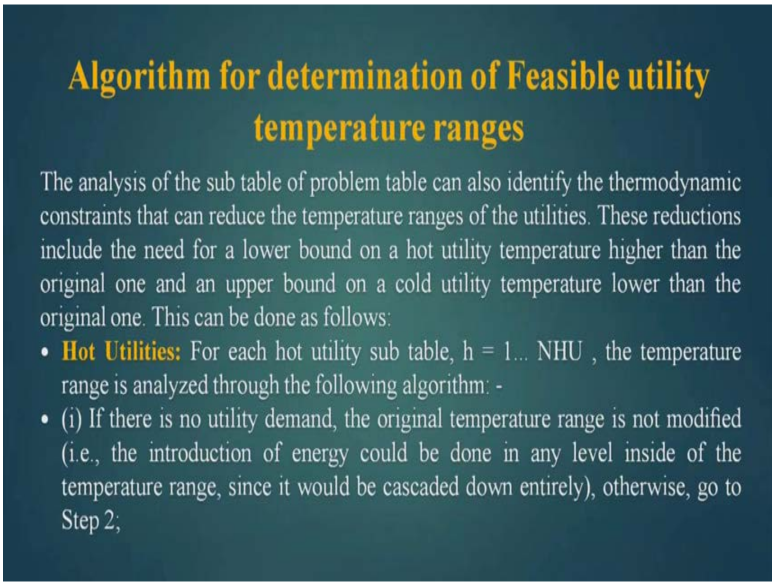

The analysis of the sub table, of sub table can also identify the thermodynamic constraint, that can reduce the temperature ranges of the utilities. These reductions include the need for a lower bound, on a hot utility temperature higher than the original one. And an upper bound on a cold utility temperature, lower than the original one.

This can be done as follows, for hot utilities for each hot utility sub table 1 to NHU, the temperature range is analyzed through the following algorithm. If there is no utility demand, the original temperature range is not modified because the introduction of energy could be done in any level inside of the temperature range. Since, it would be cascaded down entirely.

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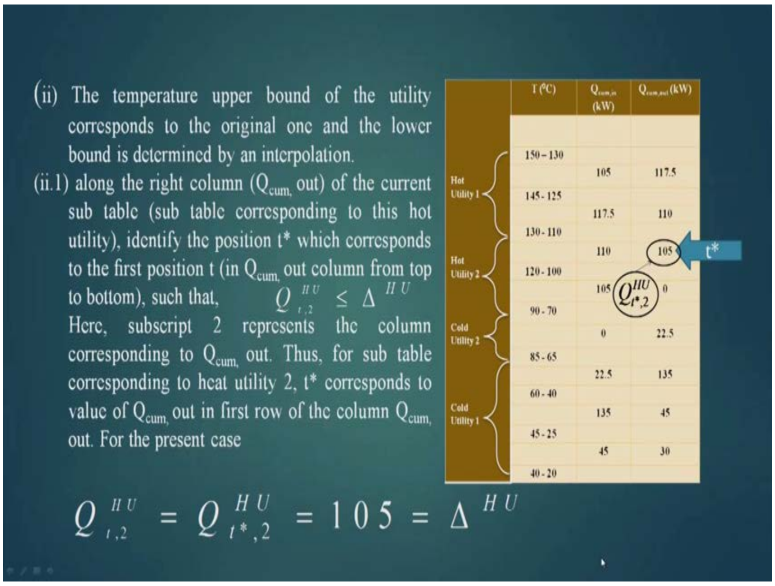

Otherwise, we have to take this step 2, which is step 2 here, the temperature upper bound of the utility corresponds to the original one and the lower bound is determined by an interpolation. For this interpolation, along the right column, this is the right column, along the right column that is Q cumulation out, of the current sub table. So, if I am working in sub table 2, this is the values which I will work for so corresponding to identify the position t star, which corresponds to first t in Q cumulative out column, from top to bottom such that, Q t 12 HU is less than or equal to delta HU.

In our case delta HU is 105 so in this column I will come from top to bottom so at the top I get 105 here. So, this is the point t star because this condition is satisfied, this condition is satisfied Q 12 HU is 105, delta Hu is 105. So, this condition is satisfied and hence, this is the t star point, here subscript two represents the column corresponding to Q cumulative out. This is the column, which is an question and this is represented by subscript two, thus for sub table corresponding to heat utility 2, t star corresponding to be value of Q cumulative out in the first row of the column. And hence this is the value Q t star 2, this this is the value 105 is equal to delta HU, which is the hot utility requirement in this case. Because, for the utility numbered 1, the hot utility requirement is z0ero and that is why delta HU is 105.

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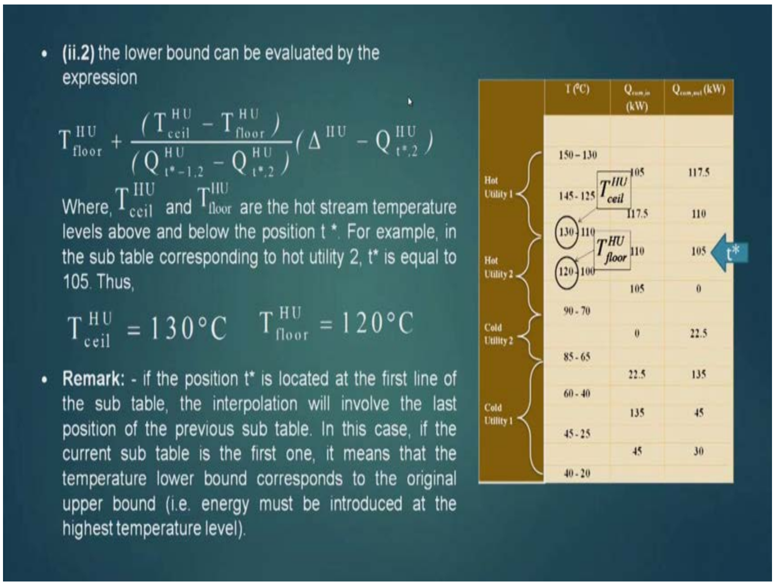

Now, the lower bound can be evaluated by the expression, this is the expression to compute the lower bound of the hot utility where, T ceiling HU and T floor HU are the hot stream temperatures, levels above and below the position t star. Now this is the t star position, if I draw a line here this is above and this is below. So, this is the hot temperatures we are dealing with and when we will compute the cold temperature, will go for this. So, in this case 130 is the T ceiling and 120 is the T floor HU.

So, this is the line and above is this and below is this so T ceiling is 130 and T floor is 120. The remark is that, if the position t star is located at the first line of the sub table, the interpolation will involve the last position of the previous sub table. That means, if it is in the first line then the interpolation can used a data from the above sub table, that is here 110. In this case, if the current sub table is the first one it means, that the temperature lower bound corresponds to the original upper bound.

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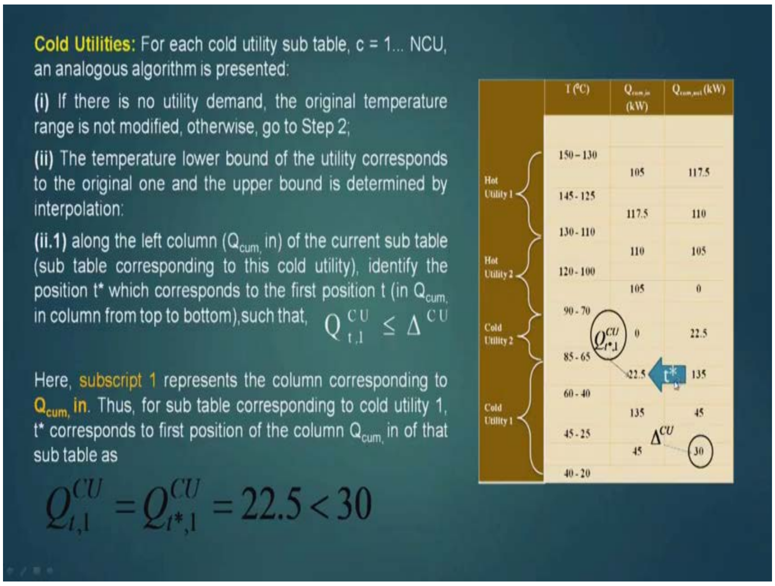

Similarly, we can add for the cold utilities, if there is no utility demand the original temperature range is not modified otherwise, we have go to step 2. The temperature lower bound of the utility corresponds to the original one and the upper bound is determined by interpolation. Here we are, through interpolation we are finding out the upper bound of the cold utility, along the left column now, you leave this column which is Q cumulative in.

So, remember for hot utility we have used this column, for cold utility will used this column and for cold utility will use this values, which are cold stream actual temperature values. Along the left column Q cumulative minimum of the current sub table, identify the position t star, which is corresponds to the first position T in Q cumulative in column from top to bottom.

So, here this is the top to bottom will go, so this is the temperature, this is the value which satisfied equal delta TCU value is 30 because there is no consumption of cold utility below this. So, this is 30 and this is 30 is greater than 22.5 and that is why this is the value denoted by t star and this is Q t star 1 CU. One stand for this column, so this condition is satisfied and hence, this is the t star value. Here subscript 1 represents the column corresponding to Q cumulative in thus, for sub table corresponding to cold utility 1, t star corresponds to first position of the column Q cumulative in of that sub table. So, this is Q t comma 1 CU is equal to t star comma 1 CU is equal to 22.5 is greater than, 30, 30 is greater than this and 30 is the value of delta CU.

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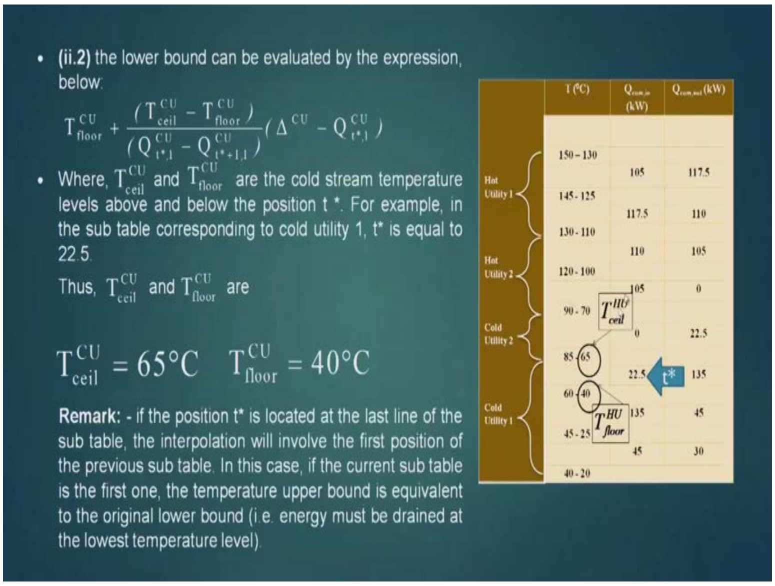

So, this is my t star value now, again as we have done in the case of hot utility to find out the amounts. Here we will use this, by this expression where T ceiling and T floor are the cold stream temperature levels above and below the position t star. For example, in the sub table corresponding to cold utility 1, t star is equal to 22.5, this we have seen. So, if we, I see the table above is 65 and below is 40 so T ceiling for cold utility is 65, T ceiling for, T floor for cold utility is 40, it is wrongly written T HU, this is should be CU, this should be CU. So, this is 65 and 40.

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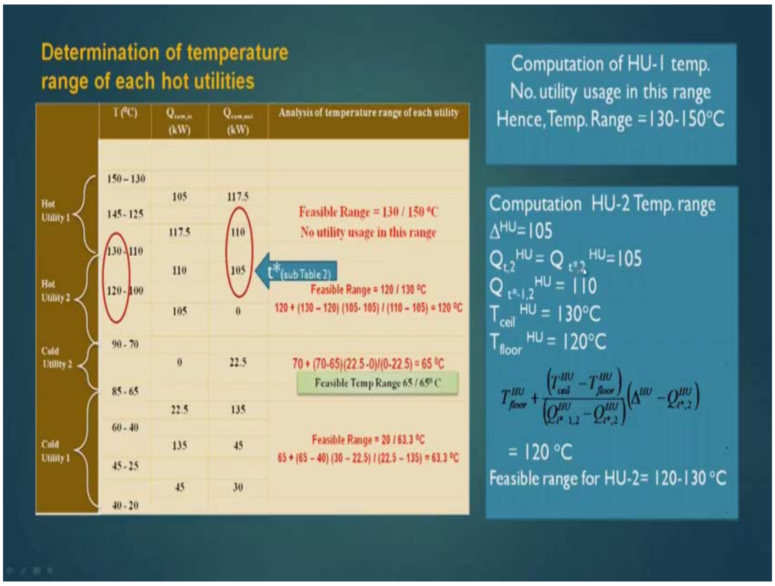

Now, we can compute the temperature ranges now, for the computation for the hot utility 1, temperature no utility uses in this range. Because, we have computed that no hot utility is required in this range that is 130 to 150. So, the range is 130 to 150 because 150 is the highest temperature and 130 is the transition temperature of hot utility 1 to hot utility 2. So, HU once range is 130 to 150 it remains and there is no consumption of hot utility in this range. So, we will calculate the for hot utility 2 so for hot utility 2 temperature in hot delta HU is 105, this we have already computed Q t 2 HU, Q t star 2 HU is 105, this we all know and computed Q t minus 12 HU is 110. So, this is the, a t star now, t minus t star minus 1 is this value, it is the, in the first entry.

So, minus 1 entry is taking from the above table, this is 110 to this taken as 110 now, T ceiling is 130, T floor is 120 so this is 130, 120. This is our equation, if I put these values are all known to me, if I put these values, all these values are here then I find that, this is 120 degree centigrade. So, the feasible range for HU 2, which is hot utility 2 is 120 to 130 degree centigrade.

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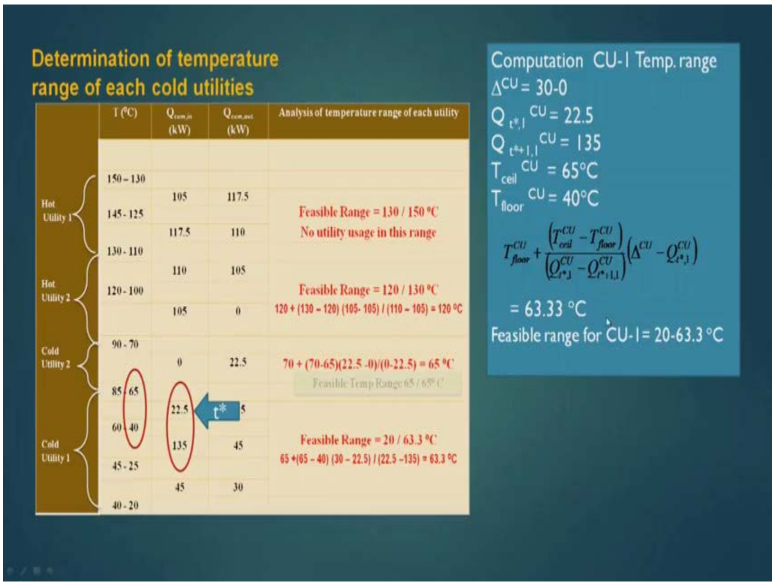

Similarly, we will compute for cold utilities now, if I compute for the cold utility 1 temperature range, delta CU is 30 minus 0 Q star 1 CU is 22.5, this we have already computed in the earlier slides. t star plus 1 i is 135, if you see here that is t star and this is t star plus 1 and the above is t star minus 1. So, t star minus 1we have used for hot utility computation and for cold utility computation, it is t star plus 1, which is these value. T ceiling is 65, this is T floor is 40 this value so all the data is available to compute this expression.

And when we compute this, it comes out to be 63.3 degree centigrade. So, feasible range for cold utility 1 is 20 63.3 degree centigrade, 20 is the lowest temperature so from lowest temperature to 63.3 degree centigrade is the feasible range of cold utility 1. We can use any temperature within this range, if some cold water is available within this range of temperature, we can used as cold utility 1.

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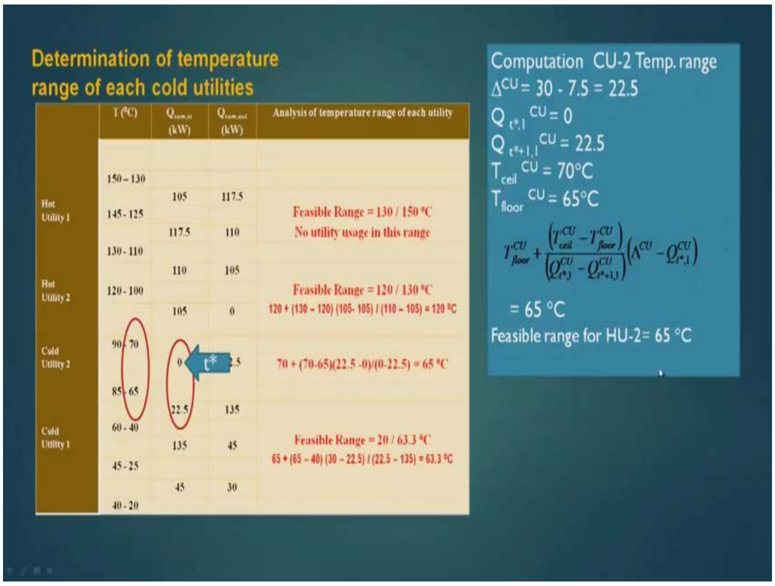

Now, for cold utility 2 let us compute, the computation of cold utility 2, temperature range. So, in this case delta CU is equal to 30, which is the cold utility requirement and consumption of cold utility in the previous sub table is 7.5. So, delta CU comes out to 22.5 this is Q t star CU is equal to 0. Here this is 0 and Q t star plus 1 CU is the next lower value here, this is 22.5. And if I go here, this is T ceiling CU is 70 and T floor CU is 65, these are two temperatures which are one above and one below this. So, this is the value so when these values are known to me, I can use this equation. So, I calculate this becomes 65 degree centigrade. So, feasible range of this is CU 2, this is CU 2 is 65 degree centigrade so this is my results.

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Consumption and temperature range of diffident hot and cold utilities determined using extended problem table algorithm

Utility	Minimum Consumption (kW)	Utility Temperature Range (°C)
Hot-1	0	130-150
Hot-2	105	120-130
Cold-1	7.5	20-63.3
Cold-2	22.5	65

So, hot utility numbered 1 the consumption is 0 range is 130 to 150, hot utility numbered 2 the consumption is 105 kilowatt and the range is 120 to 130. Cold utility numbered 1, the consumption is 7.5, the range is 20 to 63.3 and cold utility 2 the consumption is 22.5 and the… It can be given only at one temperature that is 65 degree centigrade. Now, we can placed this in a grand composite curve because grand composite curve is a curve in which, multiple utilities are placed and this has been created for that. So, let us place it.

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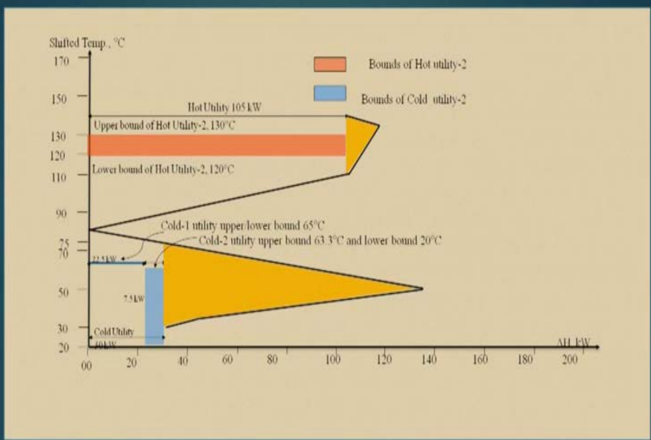

Placement of multiple utilities computed by extended problem table algorithm on grand composite curve

So, this is my grand composite curve I can used the hot utility at this temperature, the maximum temperature, the requirement is 105 and cold utility at a lowest temperature, my requirement is 30 kilowatt. And this is a shifted temperature now, this shows the bound of hot utility 2, the highest temperature is 130 degree centigrade and lowest temperature is 120 degree centigrade. So, we can use the hot utility in any temperature between this two temperatures. Similarly, this is cold utility 1, there is large range for this so this is cold utility 1, which range is 20 to 63.3 degree centigrade. This is cold utility 1, not 2 and this is cold utility numbered 2, this is not 1 this is 2 which is 65 degree centigrade. The amount of cold utility numbered 1 is 7.5 kilowatt and amount of cold utility 2 is 22.5 kilowatt and it will be delivered at 65 degree centigrade and cold utility 1 can be delivered from 20 to 63.3 degree centigrade.

So, at any temperature we can delivered this. So, what we have understood that a, the same PTA can be used to find out, different hot utilities and different cold utilities. If we know the transition temperatures, of these hot utilities and cold utilities, which is easier to find in a industry. While these transition temperature are known, we can used this modified PTA to find out the amount of these utilities and their temperature ranges, which is very beneficiary for us. Otherwise, we have to use the GCC to find out these hot and cold utilities.

Thank you.