Process Integration
Prof. Bikash Mohanty
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Module - 4
Targeting
Lecture - 2
Problem Table Algorithm – First Part

Welcome to the lecture series on Process Integration. This is a module four, lecture two; and the topic of the present lecture is problem table algorithm. This is the first part of the lecture.

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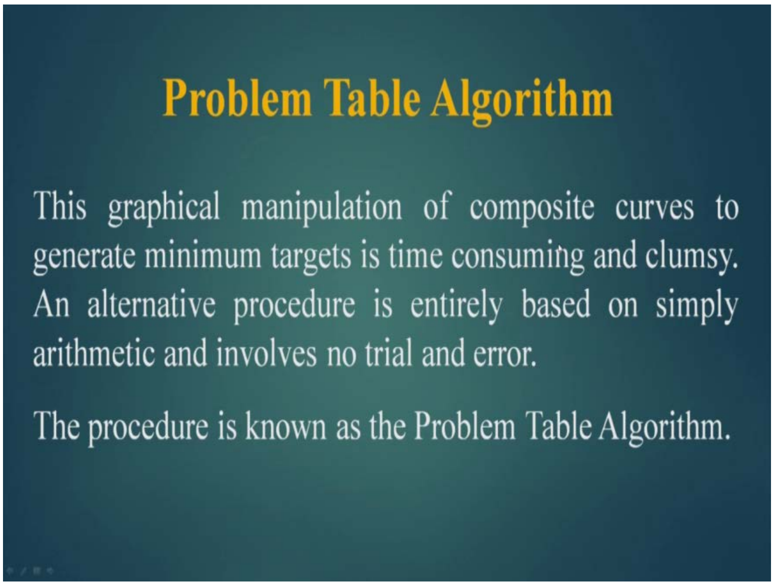

The graphical manipulation of composite curves to generate minimum targets is time consuming and clumsy. That we have been seen to find out the energy target, we have gone through it graphical representation in which we have plotted the composite hot and composite cold curves and then shifting the composite cold curve toward the composite hot curve of to maintain the delta T minimum of a certain value. We have calculated the hot utility requirement and cold utility requirements. However, if the numbers of hot streams are very high and cold streams are also high, then leading such a graphical method is cumbersome. Further this graphical method has to be operated by a computer and thus a alternative procedure is suggested which is based on simple arithmetic and involves no trial and error. This algorithm can be converted into computer algorithm and can be very well used by the computer. This procedure is known as the problem table algorithm.

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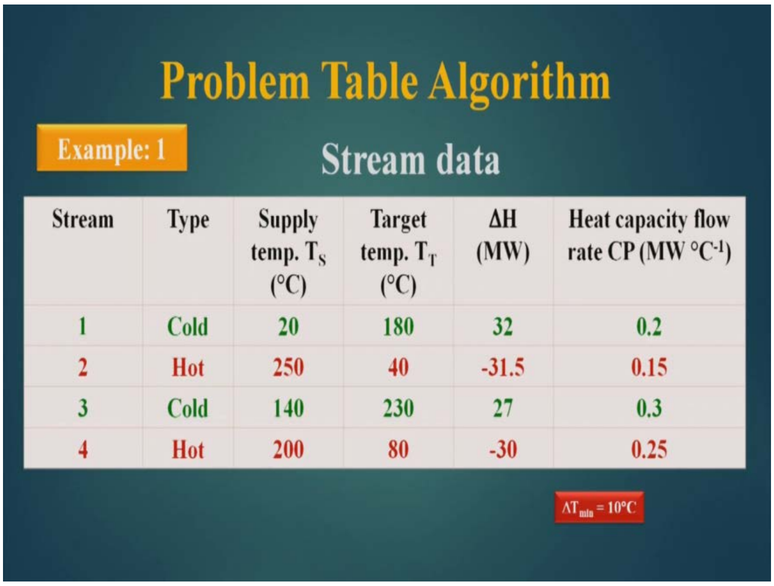

Stream	Type	Supply temp. T_S (°C)	Target temp. T_T (°C)	ΔH (MW)	Heat capacity flow rate CP (MW °C^{-1})
1	Cold	20	180	32	0.2
2	Hot	250	40	-31.5	0.15
3	Cold	140	230	27	0.3
4	Hot	200	80	-30	0.25

To show you how to use problem table algorithm, we have taken a stream data as given in example one. It has two cold streams and two hot streams, the supply and target temperature streams are given the CP value which is heat capacity flow rate is also given and delta H values are calculated and filled up in this table. The delta T minimum considered for this stream table is 10 degree centigrade.

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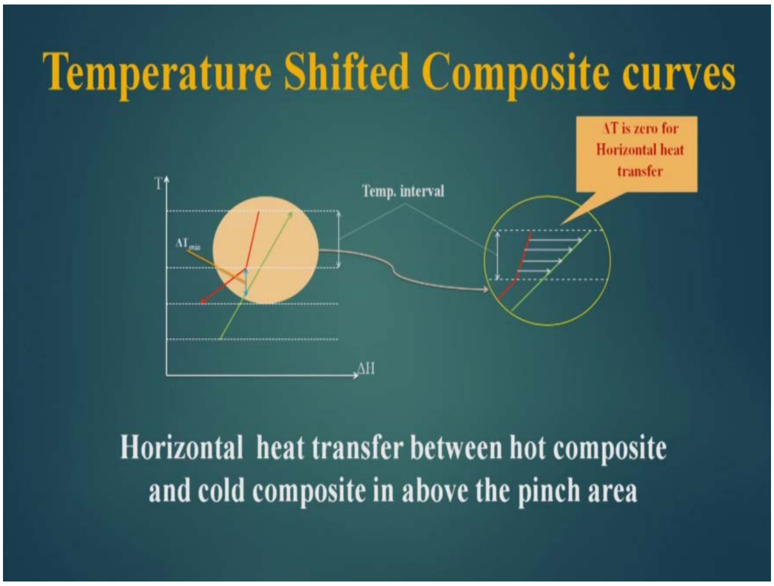

Now, let us draw this data available in this stream table. In a T-H diagram the red one shows the composite hot curve and the green one shows the composite cold curve and the minimum distance between hot composite hot and composite cold is this, which represents delta T minimum. Now let us take this upper part of this and draw it. Now, if I try to have a horizontal heat transfer from composite hot to composite cold then delta T available for this transfer is zero, because I am drawing lines perpendicular to T axes and thus the temperature for this horizontal heat transfer. The temperature draw for this horizontal heat transfer is zero, and the temperature remains constant during this horizontal heat transfer. So, these types of heat transfer is not possible.

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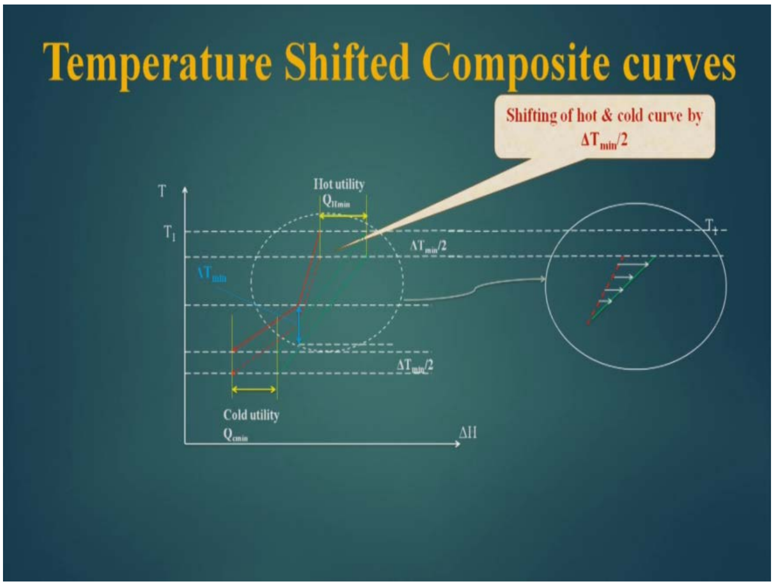

Now to make it possible I have to do some arrangements or some alternative arrangements. Now in this arrangement, what is being done that the composite hot stream is vertically shifted downward by an amount T minimum by 2, and the composite cold composite curve is shifted upward by an amount T minimum by 2. Now, while doing so as the curves are shifted vertically, the distance between extreme part of the hot composite and cold composite curves remain constant. And that is why the hot utility prediction, which is Q H minimum and the cold utility prediction which is Q C minimum remain same. Though, the hot composite curve is shifted downward by delta T minimum by 2, and cold composite curve is shifted upward by an amount delta T minimum by 2. Now, when we do this the hot composite curve touches the cold composite curve at delta T minimum and this point is nothing but the pinch point. Now if we do so and then the upper part of the pinch, and try to do the horizontal heat transfer in this case, then horizontal heat transfer is permissible.

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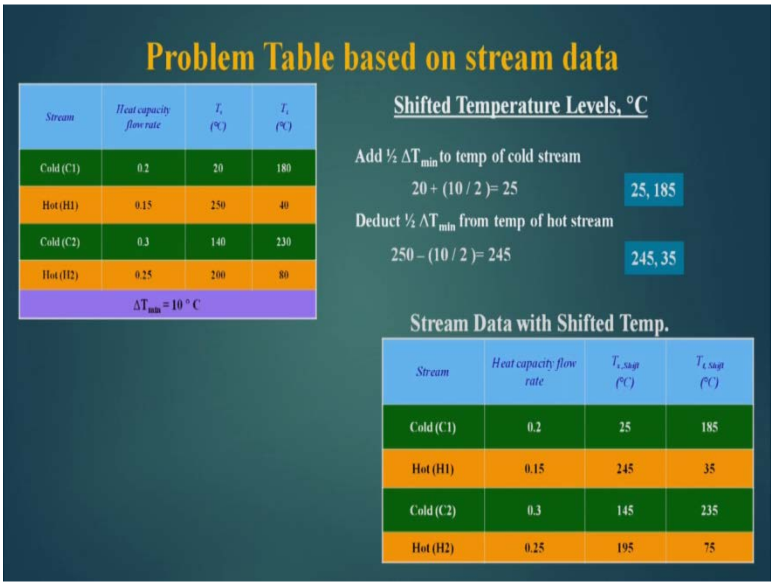

Because now the temperature difference is delta T m during the horizontal heat transfer and hence horizontal heat transfer is permissible. A based on this logic, the problem table algorithm has been devised and let us takes an example and demonstrates this problem table algorithm for this we take an example where there are two cold streams and two hot streams and delta T minimum is ten degree centigrade. Now, first job is to convert the temperature levels into shifted temperature levels for this purpose we will add delta T minimum divided by two to the temperatures of cold stream and will deducted the delta T minimum by two to the temperatures of hot stream and this is as we are shifting the hot stream in the downward direction and raising the cold stream in upward direction by an amount delta T minimum by two which we have already demonstrated in the earlier plot.

Now, if we apply this to cold stream c one then the supply temperature of the cold stream c one is twenty degree centigrade now delta T minimum is ten degree centigrade. So, delta T minimum divided by 2 is 5 and the we add up this 5 to 20 degree centigrade becomes 25 degree centigrade.

Similarly, the target temperature is 180. So, when we add 5 degree centigrade to 180 it becomes 185. So, the two actual temperature levels of the cold stream C 1 which was 20 and 25 is now converted into temperature shifted temperature level and given by 25 and 185.

Now, we deduct delta T minimum by two from the temperature of hot stream for this purpose we take h one as the hot stream and the supply temperature is two hundred fifty we deduct delta T minimum by two which is five degree centigrade from it.

So, it converts into two forty five degree. So, the supply temperature of h one is now two forty five degree and the similarly if you compute the target temperature which is forty now that becomes thirty five. So, when we convert the actual temperature of h one to shifted temperature level they become two forty five and thirty five in the similar manner all the temperature levels were converted into shifted temperature levels and given in the table shown in the bottom. So, that is twenty five one eighty five one two forty five thirty five one forty five two thirty five one ninety five and seventy five.

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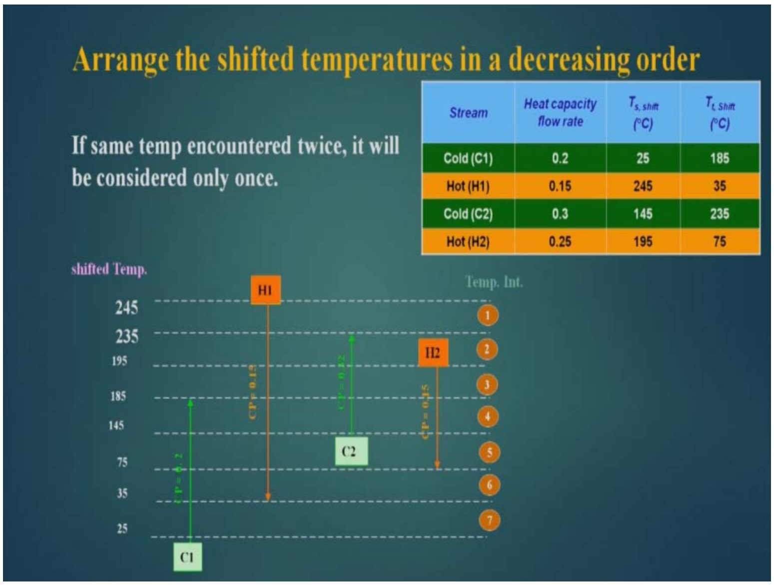

Now these temperature levels are put in the decreasing order and if a temperature level in encountered twice it will be consider only once. So, in this case the if you plot the temperature levels. So, the highest temperature level is two forty five and then next highest is two thirty five and then next highest is one ninety five and so on so forth have to twenty five degree centigrade.

So, we number this temperature intervals two forty five to two thirty five is one two forty five to two ninety five is two, and so on so forth. So, we have seven temperature intervals in this case now we draw the cold and hot streams in this temperature intervals the cold stream c one moves from temperature interval twenty five to one eighty five.

Ah we should understand that the temperature which have been given for the temperature interval are all shifted temperature. So, c one moves form twenty five to one eighty five similarly the c two h one moves now from two forty five to thirty five the c two moves from one forty five to two thirty five and h two moves from one ninety five to seventy five.

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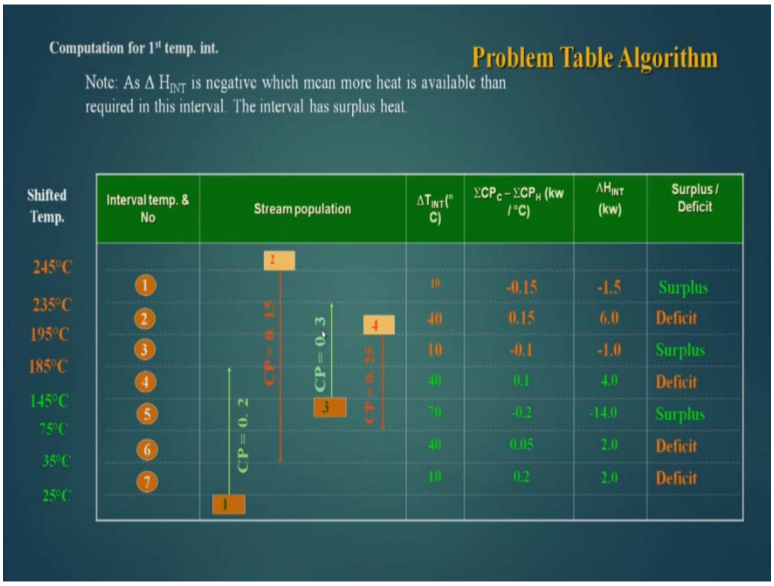

Now, to exhibit the problem table and algorithm we have to this table in which there is interval temperature and number stream population delta T interval and then summation of c p c minus summation of c p h and then delta h interval and then we have surplus or deficit to fill up this table we take this shifted temperatures and then we define the temperature interval numbers in as done in the earlier site then we show the stream population in different temperature intervals and then we fill up the last four columns by doing calculations.

So, we take of the first interval which starts at two forty five and ends at two forty five. So, delta T interval is two forty five minus two thirty five is equal to ten degree and this ten degree transferred here at this position and then we compute delta c p c minus delta c p h. So, here it needs some understanding.

In this temperature level which is temperature level one only one stream is that that is hot stream which stream number is two. So, there is no cold stream here. So, summation c p c is zero because there is no cold stream available in this temperature interval whereas, there is one hot stream which c p value is zero point one five and that is why summation c p h will be zero point one five and hence the total value is minus zero point one five

And this will move to this position then we multiply this temperature interval with this value then we get the delta h interval which comes out to be minus one point five now this shows that as delta h interval is negative which means more heat is available than required in this interval, so this interval as a surplus heat. So, this moves to surplus it becomes surplus and this is clear from the interval that there is only one hot stream which is ready to give heat in this temperature interval there is no cold stream to takes this heat.

So, this heat remains as it is and this can be transfer to lower temperature level and that is why this much amount of heat is surplus mine in the similar manner if you see in the temperature interval which is number two the temperature moves from two thirty five to one ninety five and the delta T is forty and the c p c summation c p c minus c p h is point one five and delta h interval is six and this is a deficit. That means in this temperature interval only the hot stream which stream number is two is available and as well as the cold stream which stream number is three the hot stream the cold stream whose stream number is three is available.

So, whatever heat which is available with hot stream is not enough to heat the cold stream that is stream number three and hence that is requirement of six kilowatt in this temperature interval and that is why it is deficit. Similarly, in this temperature interval that is number three two hot streams are available to give heat and once cold stream is available to take heat and the heat available with hot streams in this temperature interval three is more than the heat required by the cold stream in this temperature interval

And that is why one kilowatt extra heat is available in this temperature interval and that’s why it is surplus in this manner we can compute the heat available or required in this temperature level one to seven and they are giving here. So, in the first interval surplus it is available in the second interval it is deficit in the third interval it is again surplus fourth interval it is deficit and fifth interval it is surplus and sixth and seven interval it is deficit now as per the rule of thermodynamics this surplus amount of heat available in a temperature interval which is at higher temperature can go down can go down, but this surplus can go out it cannot go out because heat can only transfer from a higher temperature to a lower temperature not from a lower temperature to a higher temperature.

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Keeping this in mind and taking out the value of delta h interval we can create a casket which starts from two forty five degree centigrade a to two forty five degree centigrade and ends at twenty five degree centigrade. This is the line twenty five degree centigrade now you can fill up one by one into this. So, all these temperature intervals are here and the first interval is this second interval this third interval this forth this fifth sixth seventh now whatever heat is comes from the top will be a hot utility and whatever heat will cross this twenty five degree centigrade level will be cold utility requirement. So, our job is now to find out that what will be the hot utility requirement and what will be the cold utility requirement for this purpose.

Now, if I want to take out the heat which is h equal to minus one point five the minus sign shows is surplus amount it can be taken to the next temperature interval which is temperature interval number two this is permissible because heat naturally will flow from a higher temperature to a lower temperature, but if you try to do the reveres; reveres is not possible I cannot take this six megawatt which is available here to this. So, it is not permitted now.

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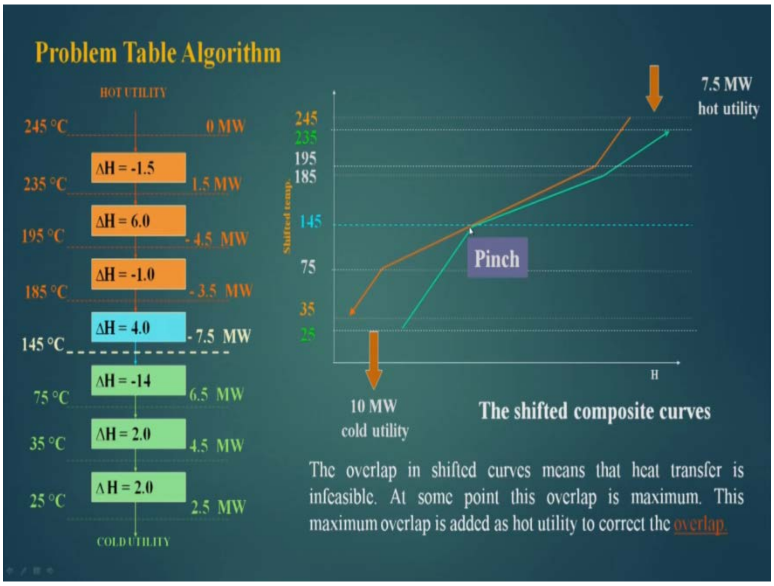

So, suppose we are adding zero megawatt from the top; that means, hot utility requirement is zero megawatt now if you do. So, then here this is zero minus minus one point five which becomes one point five megawatt So, at this temperature level one point five megawatt is passing to downward similarly if I can I can calculate this values here this is one point five minus six point zero. So, this becomes minus four point five megawatt and then here this is minus four point five minus minus one point zero it becomes three point five minus three point five megawatt here

And here this is minus three point five minus four point zero it becomes to minus seven point five here in similarly I can calculate the heat which is pass through different temperature levels now here I find that the maximum negative value is minus seven point five megawatt. Now, this I have done through a algebraic calculation, but the question is what is the meaning of this in terms of composite curves can I translate this to a real composite curve and confined out the relationship between this two.

If I do, so here you see that is the hot composite curve and cold composite curve and at this end they match meaning that the hot utility demand is zero in this case also hot utility push to the system is zero megawatt and these values shows that the cold composite curve is above the hot composite curve for a considerable duration of length.

From here to here it is over the hot composite curve and these distance this horizontal distance is minus seven point five megawatt in the previous lectures I have clearly told that if a feasible retransfer to takes place the composite hot curve should be above the composite cold curve. So, that heat transfer takes place from hot to cold now in this situation this is not possible for all part of the heat of the composite curve to give heat to all part of the cold composite curve.

In fact, it shows as if heat is pass from cold composite curve to hot composite curve and that is why it is a infeasible solution now to make it feasible this cold composite curve has to be shifted horizontally. So, that it becomes below the cold composite curve.

So, we shifted. So, that it touches the hot composite curve at the pinch point and all the temperatures are shifted temperatures at this pinch point the delta T minimum is equal to the delta T minimum it is not zero because the hot composite curve has been shifted downward by delta T minimum by two and the cold composite curve has been shifted upward by delta T minimum by two.

So, even if they join at a point the actual temperature difference at that point is delta T minimum. So, even if these two composite curves which are shifted temper temperature verses delta h are touching at pinch point that will be heat transfer at this point. Now, it shows that when you transfer horizontally the gap is generated between these two and this gap is seven point five megawatt of hot utility and similarly it shows that it needs ten megawatt of cold utility now this situation which is a feasible situation has to translated to this and the question is what we should.

In which way we should operate that this which is a non feasible solution converts into a feasible solution and the solution represent this state of the hot and cold composite curves let us see how to do it and when we will do this then cold utility requirement will be ten megawatt and the hot utility requirement will be seven point five megawatt.

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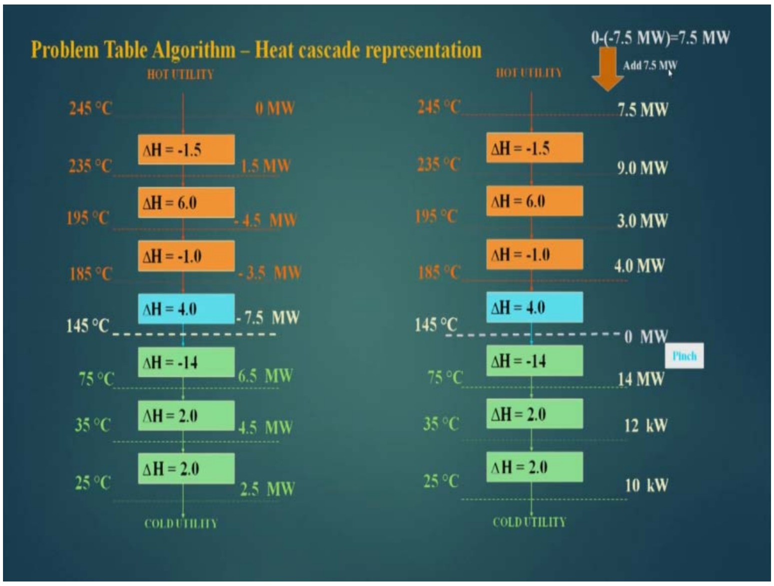

Now, we search here that what is the maximum negative quantity the maximum negative quantities minus seven point five megawatt. So, if I pass seven point five megawatt of heat from the highest temperature level then it will be able to give heat to all the temperature levels below and when it percolates down or castrates down to this point the heat requirement of this will be zero

So, we pass now the maximum value from the top. So, we add seven point five megawatt from the top level that is level of hot utility it will be at temperature of hot utility which will be; obviously, the more than two forty five degree centigrade and if I consider delta T minimum to be ten degree centigrade then the level will be two fifty five degree centigrade and this will be also a shifted temperature.

So, a shifted temperature up at least two fifty five degree centigrade from that temperature level heat of seven point five megawatt will be pass to this caskets if I do this the seven point five megawatt passes to forty five temperature level and here it becomes nine megawatt and then this becomes three megawatt. This becomes four point zero megawatt and this becomes zero megawatt and. So, once this is zero megawatt; that means, the temperature through temperature level of hundred forty five degree centigrade zero megawatt cross.

And hence it is the pinch temperature, but this four one hundred forty five degree centigrade is a shifted temperature it is not the actual temperature. So, to find out pinch temperature hot pinch temperature will add delta T minimum by two to this. So, it becomes hundred forty hundred fifty degree centigrade and for the cold we will do reveres; that means, we will deduct delta T minimum by two which is five degree in this case and. So, it becomes hundred forty. So, hundred fifty minus hundred forty is ten degree centigrade. Basically we at doing a reverse when we are doing a shifted temperature determining the sifted temperature we are deducting delta T minimum by two from the hot and when we are reverting it we are adding delta T minimum by two.

Similarly, for the cold when we are converting cold temperature into shifted temperature we are adding delta T minimum by two, but when we are converting it to real temperature we are deducting delta T minimum by two So, the pinch temperature is one forty five and this is the shifted temperature then if we calculate this. So, we find that ten kilowatt will pass through to twenty five degree centigrade and hence the cold utility demand is ten kilowatt whereas, the hot utility demand is seven point five kilowatt in this case. So, it is a feasible case now because no in the no level the this is negative I will say that this is not kilowatt basically this is megawatt this is megawatt.

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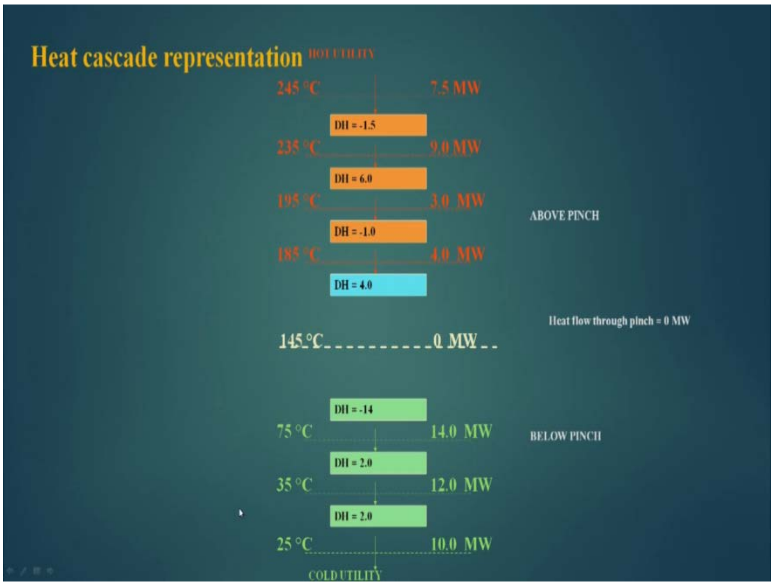

So, this is the case feasible case now as for this we say part is this part is above pinch this is d h means delta h above part is above pinch region, and this part is below pinch region and there is no heat transfer from this above pinch region to below pinch region and this is the pinch temperature level in shifted temperature.

That is why we say that pinch divides the problem into two parts and both parts are in temperature in formal balance here the heat available with the hot stream plus the hot utility is equal to the heat required by the cold stream similarly here the heat re available with hot stream is equal to the heat required by the cold stream plus cold utility. Now, we take a second example the example number two. So, we convert this actual temperatures to shifted temperatures we add two columns here in the right side.

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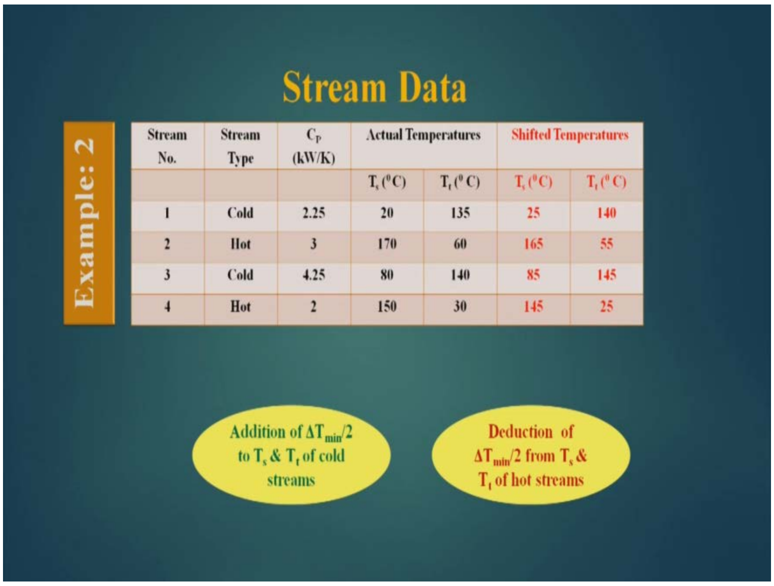

And convert them to shifted temperatures as delta T minimum is ten degree centigrade here for this example. So, we add five degree to this. So, it becomes twenty five. We add five degree to the cold stream it becomes hundred forty to we deduct five degree to hundred seventy becomes hundred sixty five we deduct five degree to sixty becomes fifty five and then it is cold stream we will add eight with five eighty five hundred forty with five hundred forty five similarly this will transform to shifted temperatures.

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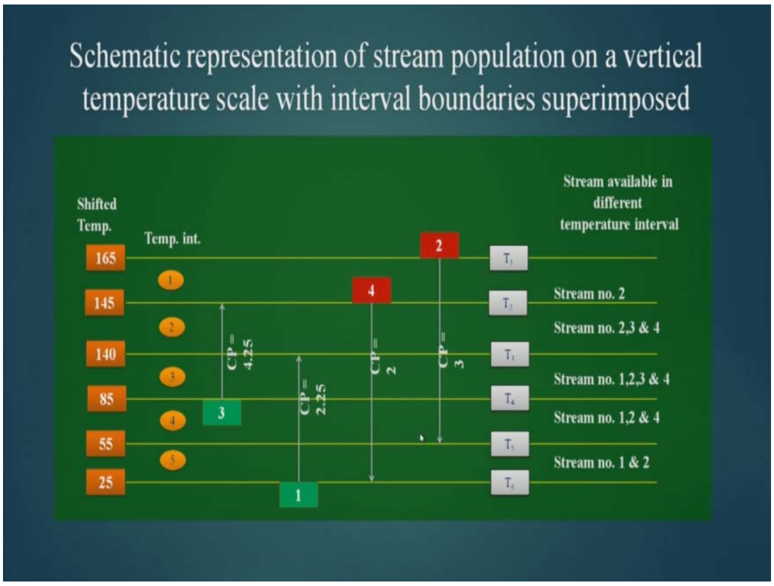

So, these are the shifted temperatures which are put in order from highest to lowest and these are the temperature intervals interval number one two three four five and six. So, the temperature intervals one two three four five and these are the temperature levels basically t one t two t three t four t five t six now you can draw the cold streams and hot streams here. So, this cold stream which is number three as got a c p value of four point two five this as two point two five c p value.

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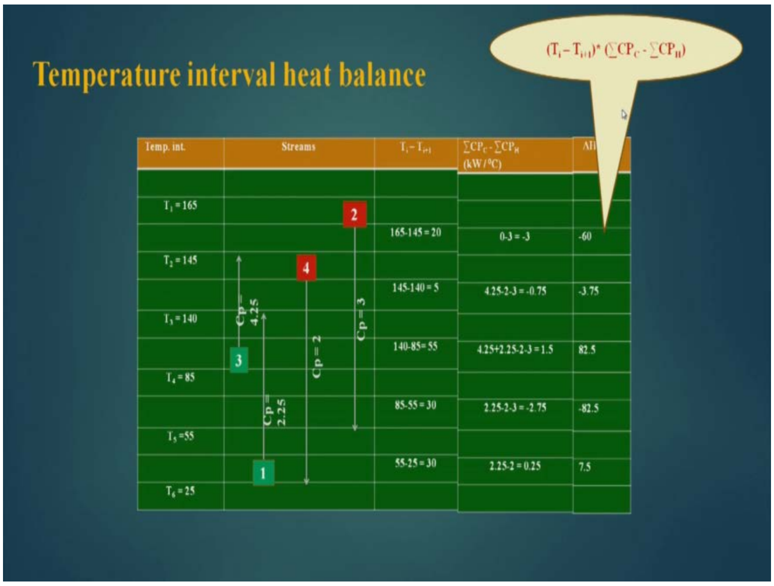

C p value two and c p value three stream available in different temperature intervals. So, here only stream number two is available in this temperature interval in this temperature interval two hot streams and one cold stream are available. So, stream number two three and four is available in this temperature interval all the four streams are available.

In this temperature interval three streams are available two hot and one cold and in this temperature interval one hot and two cold streams are available. So, the delta T temperature interval the delta T is twenty for this case for this case five this case fifty five. This case thirty and this case thirty. So, summation c p c minus c p h is point three here because this is zero minus this is here the c p c is zero and c p h is three. So, zero minus three is three here. Minus three here and in this interval there are two hot streams available and one cold stream. So, this is three plus two five five minus this is yes this is four point two five cold is four point two five minus two plus three five. So, this becomes point seven five.

Similarly, we have computed the delta c p c minus c p h values here then we have delta h values in this temperature interval delta is minus sixty this is minus three point seven five and this is eighty two point five this is minus eighty two point five and seven point five. So, this has been computed like this delta T into summation c p c minus c p h now here this is the minus sign shows the surplus this minus sign shows the surplus this positive sign shows is deficit this negative sign shows is surplus and this shows the deficit.

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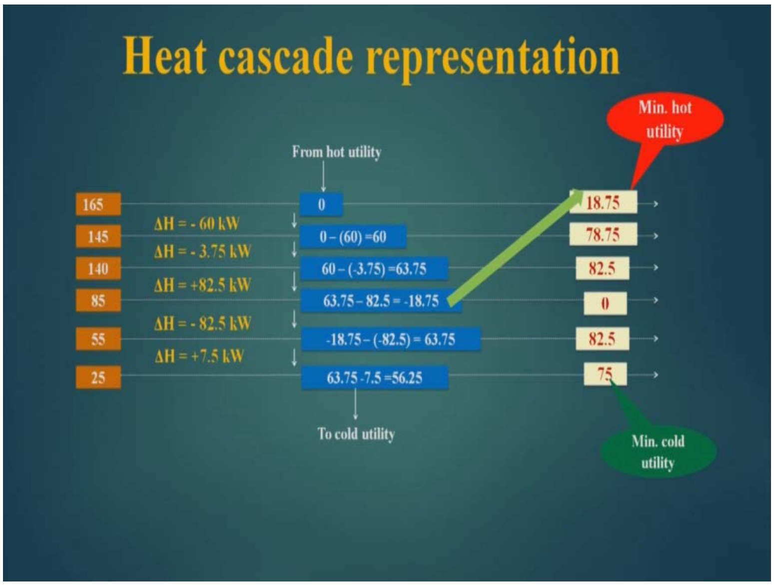

So, these are the values delta T are values available in this temperature intervals. So, we pass on zero value of it hot utility. So, in this temperature level it sixty crosses similarly we can find out that what is amount of with it crossing in different temperature levels and this goes to cold utility. Now, this is minus eighteen point five the maximum value is minus eighteen point five. So, to make this feasible this it transfer feasible we have to add eighteen point five units of heat from the top. So, we add from the top eighteen point seven five that crosses this temperature level one sixty five basically the temperature level of the hot utility will be at least one sixty five plus the minimum delta T minimum.

That means this if it is a hot stream and it will be added to five and the actual temperature will come then we will add another ten decree centigrade to find out the temperature level of the hot utility if I add this. So, at this point it becomes zero; obviously, because we have added eighteen point seven five which is minus eighteen point seven five this becomes zero and so this temperature level which is 85 is now the pinch point and to find out the hot pinch and cold pinch we have to add delta T minimum by two to this eighty five and deduct delta T minimum by two to this eighty five to know the hot pinch temperature and cold pinch temperature.

So, this clearly shows that the hot utility demand is eighteen point seven five and cold utility demand is seventy five. So, this is the minimum hot utility demand and this is the minimum cold utility demand. I have already told you that pinch during the energy targeting gives you minimum hot utility and minimum cold utility which is required.

It never talks about the maximum hot utility or maximum cold utility maximum hot utility and maximum cold utility can be anything, but it gives you the minimum required hot utility as well as cold utility and this is the pinch point; obviously, it is showing a shifted pinch point and actual pinch point has to be computed.

Thank you.