Process Integration
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Module - 4
Targeting
Lecture - 3
Grand Composite Curve

Welcome to the lecture series on process integration, this is module 4, lecture 3. The topic of the lecture is grand composite curves, let us see what is a grand composite curve and why there is a requirement for the grand composite curve.

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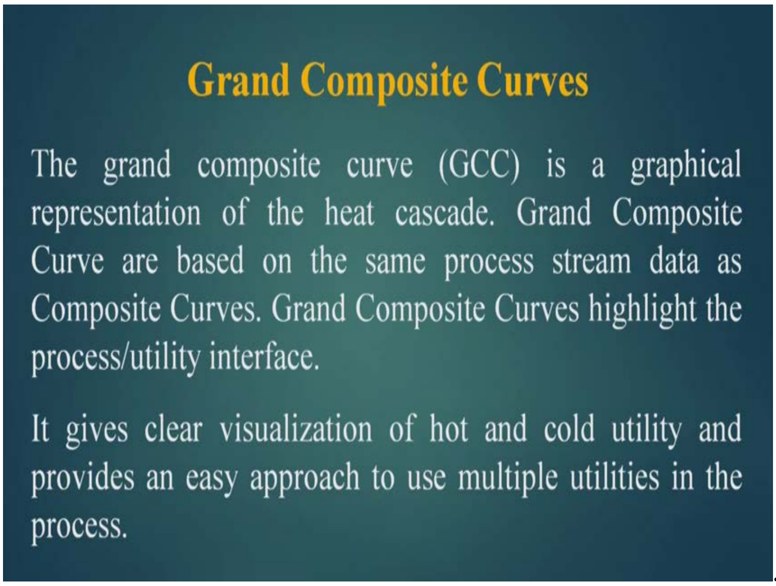

The grand composite curve, which is in short recognize GCC is a graphical representation of the heat cascade. Grand composite curves are based on the same process stream data as composite curves, meaning that from the stream table data the composite curves can be drawn. And composite curves, we can find out the values to draw the grand composite curve. The grand composite curves highlight the process utility interface, the importance of the grand composite curve is that we can find out the level as well as the quantity of different hot and cold utilities, which are require to satisfy the process conditions. It gives clear visualization of hot and cold utility and provides an easy approach to use multiple utilities in the process.

I would like to emphasize here that by using a single utility also single cold utility or single hot utility, the hot utility at the highest temperature and cold utility at the lowest temperature, we can satisfy the process conditions. However, when we use multiple utilities, if I am using multiple hot utilities, they will be at different temperatures. And if I am using multiple cold utilizes, they will be also at different temperatures. By using multiple hot utilities or multiple cold utilizes as we will see in this part of the lecture, we can bring down the operating cost, why, because a hot utility at the high temperature is costlier than a hot utility at the lower temperature.

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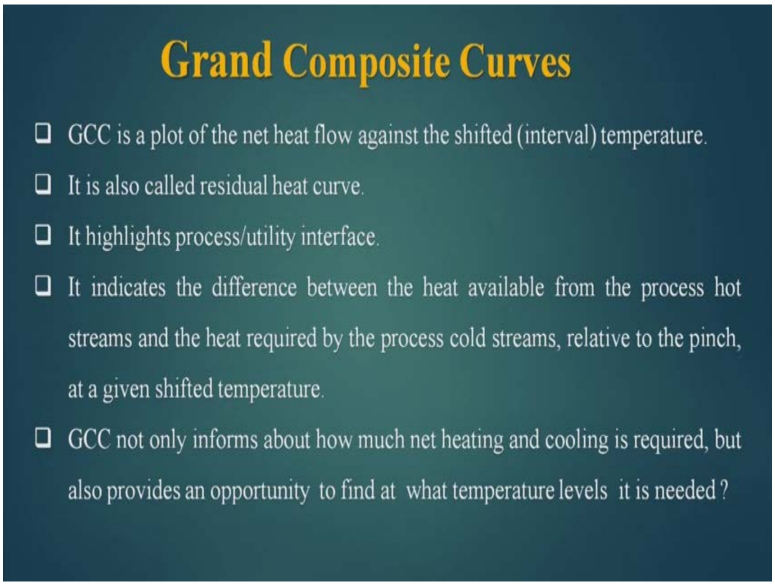

Let us see the other thinks about the grand composite curves, GCC is a plot of the net heat flow, against the shifted interval temperature. A GCC is also plotted between the shifted temperatures and delta H. It is also called residual heat curve, it highlights process utility interface, this we have explained. It indicates the difference between the heat available, from the process hot streams and the heat required by the process cold streams relative to the pinch, at a given shifted temperature.

Because the two axes, which are selected for the grand composite curves are shifted temperature and delta H. GCC not only informs about, how much net heating and cooling is required, but also provides an opportunity to find, at what temperature levels it is needed. This will be clear when we will discuss GCC. Now, GCC can be created from the data available in PTA or it can be created from composite curves, that is hot and cold composite curves. So, let us first see how GCC can be created using the data available in PTA.

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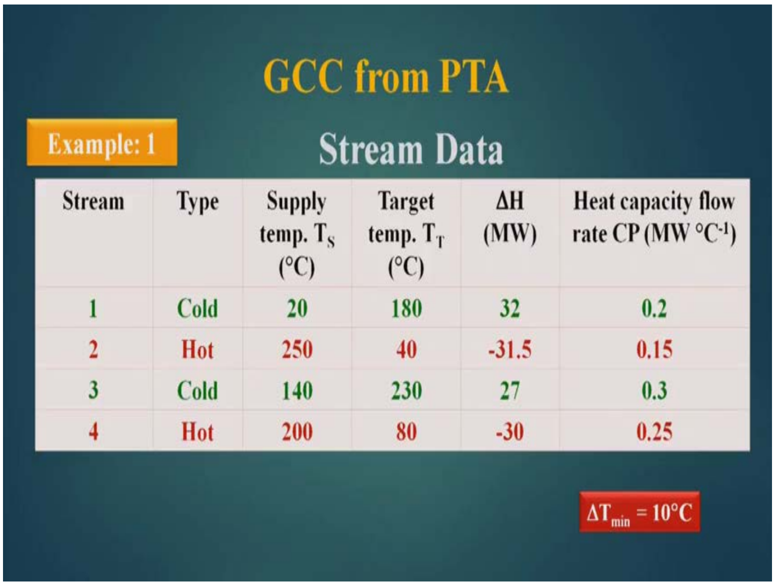

For this purpose, let us take this example 1 where, stream table data is available. In this stream data table, there are two cold streams and two hot streams where, the target temperature, supply temperature, delta H and heat capacity flow rate data are available. And delta T minimum for the stream data, is taken as 10 degree centigrade.

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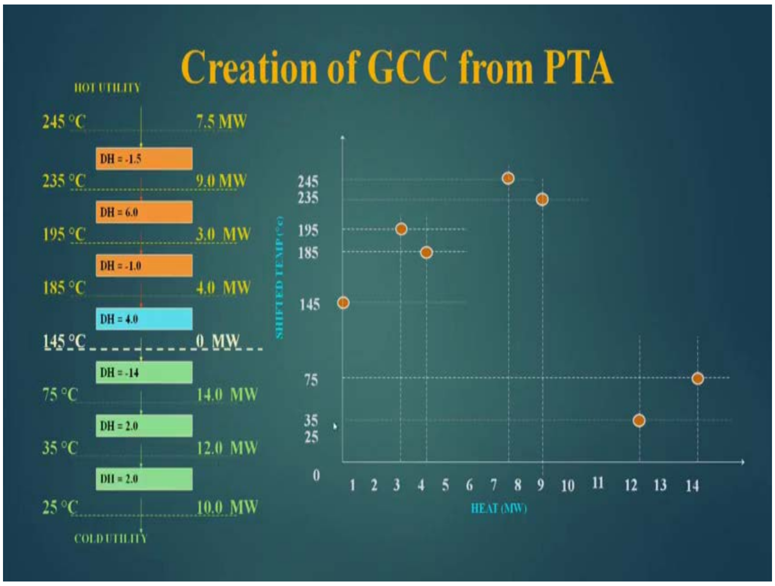

Now, this was the PTA data where d H shows you delta H value basically, and 7.5 is the hot utility demand and 10.0 is the cold utility demand. This is the feasible PTA solution as, no value in this column is negative and 0 shows that at 400, 145 shifted temperature level. The heat which passes through it is 0 megawatt and thus, this is the pinch temperature, shifted pinch temperature basically. And from here to here, this is upper pinch area and from here to here, this is lower pinch area and the problem is divided into two parts, the upper pinch area and lower pinch area. Now, these values and the temperature levels will be utilizes for the creation of GCC. So, to plot GCC this axis which is a y axis is shifted temperature and this x axis is delta H.

Now, here we will see that all temperature levels are written, which are the natural temperature levels 245, 245, 235, 195, 195, 185, 185, 145, 145, 75, 75, 35, 35 and 25, 25 and this is 0 value. Now, this temperature levels which are the shifted temperature levels have been computed from, the actual temperature levels. And for a hot stream, the shifted temperature is actual temperature minus delta T minimum by 2.

And for cold stream the shifted temperature, is actual temperature plus delta T minimum by 2. Now, this temperature levels are basically either supply temperature or the target temperature of hot stream or cold stream. To create the GCC, first we will see that at the highest temperature 245, what is the heat, we just crossing it is a 7.5 megawatt. So, we take 7.5 megawatt here and the temperature level is 45, so we get this point. Then we go for the below 235 and 9.0, so this is 9.0 and 235 then we go 195 and 3.0. So, this is 3.0 and 195. Then we go for 185 and 4.0 this is the point then we go for 145 and this is 0, which is the pinch point then we go for 75 and 14, this is 14 and this is 75. And we go for, 35 and 12.0, so this is 35 line and 12.0.

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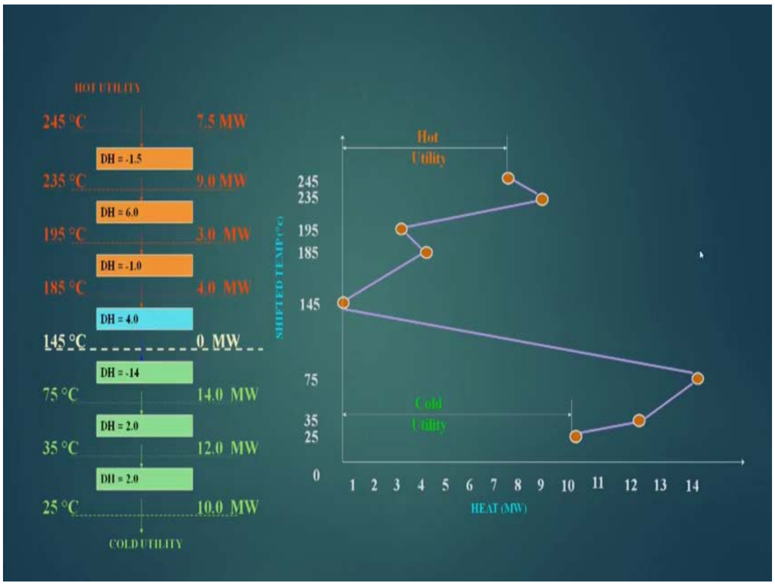

And then we have to go to 25 and 10.0, 25 and 10.0 So, we have marked the points and then we will join, so this join will be from here to here to, here, here to here, here and here, so let us join them. Now, the distance between this point and this point shows you the hot utility and distance between this point and this point shows you, the cold utility. So, this is the hot utility requirement and this is cold utility requirement of the process. Let us seem other properties of this GCC.

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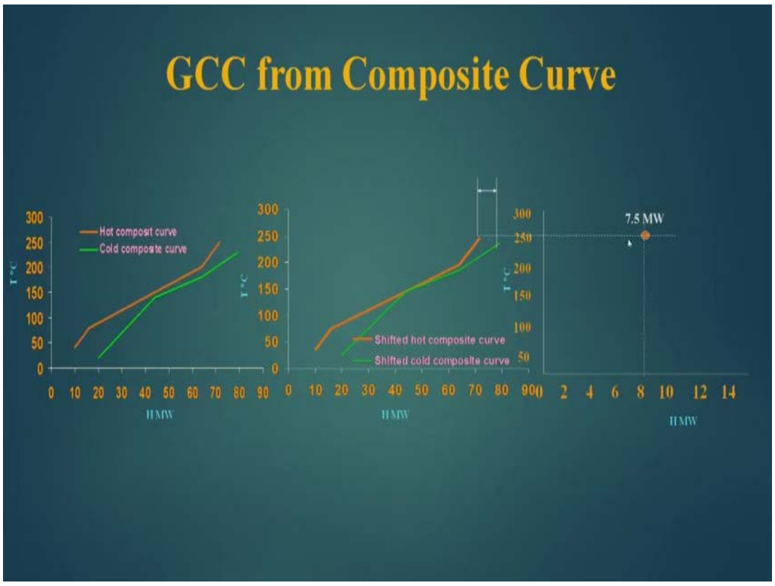

Now, the same GCC can be created from the composite curves and the method is same, we will take the different temperature levels. And we find out what is the delta H, which is crossing from there, which is basically, the distance between this and this at different temperature levels and then we will plot it. So, this is shifted temperature since the delta H, this is the first level of temperature while, the hot temperature is entering. This is 7.5 kilowatt and this is the point, temperature level it is around 250.

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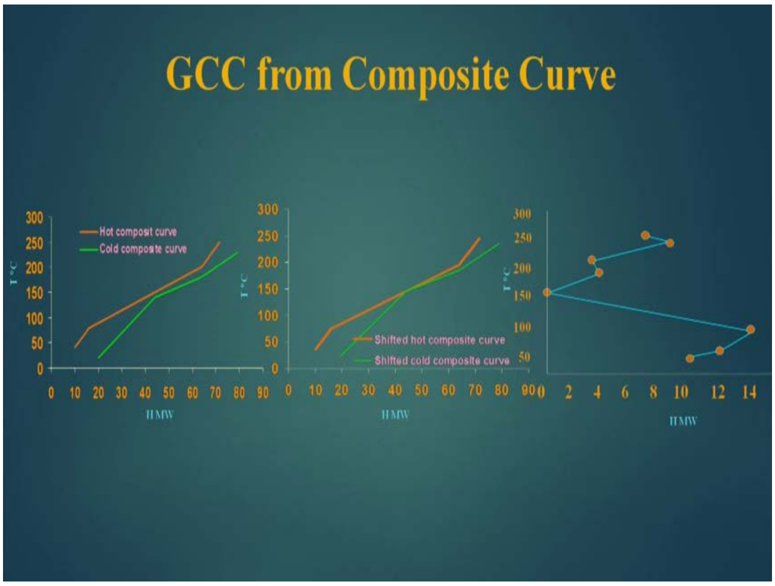

Similarly, for different temperature levels we will find out the values, this temperature level this is the gap. This is the gap, this is the pinch point, so it has to be 0. So, this is the temperature level and this gap shows the delta H value, this is the cold utility requirement and megawatt. So, what we saw now that, we can draw the GCC from the data available with PTA or we can draw the GCC, from the composite curve. Basically, the same data which is available in PTA is being picked up, from the composite curve that is, at different temperature intervals, what is the, or different temperature levels. What is the heat which is crossing that level and by plotting that we get the GCC. This is hot utility requirement, this is cold utility requirement.

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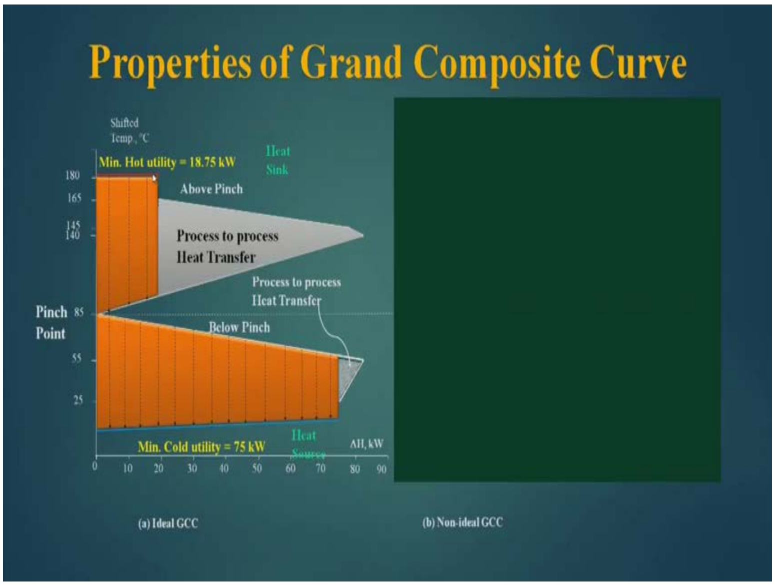

Now, let us see some properties of grand composite curve, this is a grand composite curve, this pocket shows process to process heat transfer. This pocket also shows process to process heat transfer and the distance between this point and this point, shows the requirement of hot utility, that is magnitude of hot utility required. And from this point to this point, the projection from here and to this shows the cold utility requirement. And this temperature is shifted temperature and here, while this GCC touches the y axis at a point and this point is a pinch point.

And obviously this point, which is a pinch point is represented in terms of shifted temperatures and if you want to find out, actual pinch temperature that is, actual hot pinch temperature and actual cold pinch temperature. Then we have to add with this in this case it is 85, add delta T minimum by 2 with 85, which will give me hot pinch temperature. And deduct delta T minimum by 2 from 85 which will give me cold pinch temperature.

Now this process to process heat transfer shown here, is not completed, a part of process to process heat transfer is shown by this pockets. This region above this line, is the above pinch region and below this line, is below pinch region. So, this above pinch region is a heat sink because it takes hot utility from outside into the process and in the below pinch region, heat is deliberate to the cooling water which is cold utility, so it goes out of the process.

So, it is a heat source here, the minimum hot utility requirement is 18.75 kilowatt and the minimum cold utility requirement. Now, if you see here the minimum cold utility requirement is 75 kilowatt now, the hot utility at this temperature which is more than the, highest temperature level of this GCC. And preferably it should be more by delta T minimum. Now, the heat which is available here is directly used to heat this stream from this temperature to this temperature. So, the delta T available, the value of delta T available here is very large, you see delta T available is very large. Similarly, this is the cold utility from here to here and the heat available, with this from here to here goes down to this cold utility and this delta T available is very high.

One beautiful thing with pinch is that, it spreads the delta T value properly and hence, able to save the energy. What here we find that, delta T values are very large and we have to do something with it. That means, the hot utility which I have selected or cold utility I have selected are not proper and I can select a hot utility, which has got lower than this and can satisfy my process. Similarly, I can pick up a cold utilities which is hotter than the, this cold utilities and can even satisfy my job or I can create steam in the lower part of the pinch. And can save this steam, low pressure steam to outside and can this way can decrease my operating cost. All these things, we will see later on.

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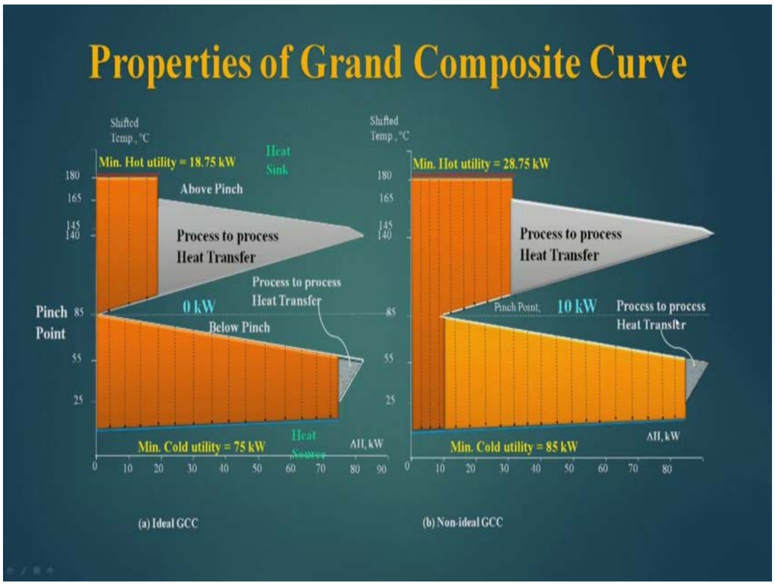

So, this is the GCC which I have shown you is a ideal GCC, but this GCC which is shown in the right hand side is not a ideal GCC. We will explain why this is not a ideal

GCC, now here the minimum hot utility requirement is 28.75, this is far more than the value here, which is 18.75. The difference between this GCC and this GCC is, this is the shifted GCC and this point is not touching the shifted temperature axis and due to this, the minimum hot utility requirement has gone up.

Now, if heat flows through it, so what we find that this amount of heat crosses through it and reaching to the cold utility, without doing any work. So, this much of it is of no used to me, but I am spending unnecessarily this much of it is directly goes from hot utility and lands on the cold utility. So, this is a non ideal GCC. So, this is, GCC clearly telling me that this much amount of it, is of no use and you are unnecessarily using this, it is not beneficiating the process yet, it is taxing the process in terms of area and the utility cost. So, here we see that the hot utility as increase and cold utility as also increase, by this much of amount.

So, if we come across such GCC curve, we will say that this is non-ideal GCC and there appears to a large scope to improve this and you can decrease the hot utility and cold utility operating cost. Here the, at pinch point 10 kilowatt was passing through this and due to this, this 10 kilowatt is added to this hot utility 18.75 plus 10 is 28.75 and 75 plus 10 is 85. So, ideally at pinch point, it should be 0.

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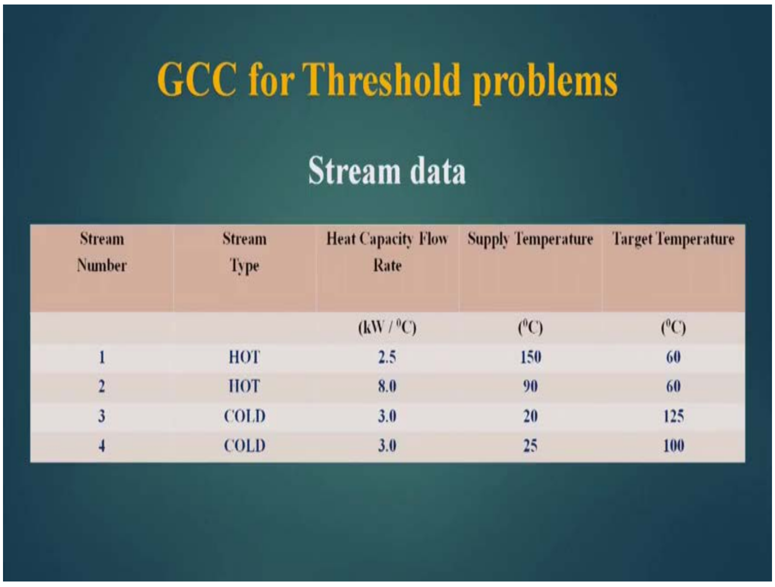

Stream Number	Stream Type	Heat Capacity Flow Rate	Supply Temperature	Target Temperature
		(kW / ^{0}C)	(^{0}C)	(^{0}C)
1	HOT	2.5	150	60
2	HOT	8.0	90	60
3	COLD	3.0	20	125
4	COLD	3.0	25	100

Now, let us see that GCC of a threshold problem, this is the stream data of a threshold problem.

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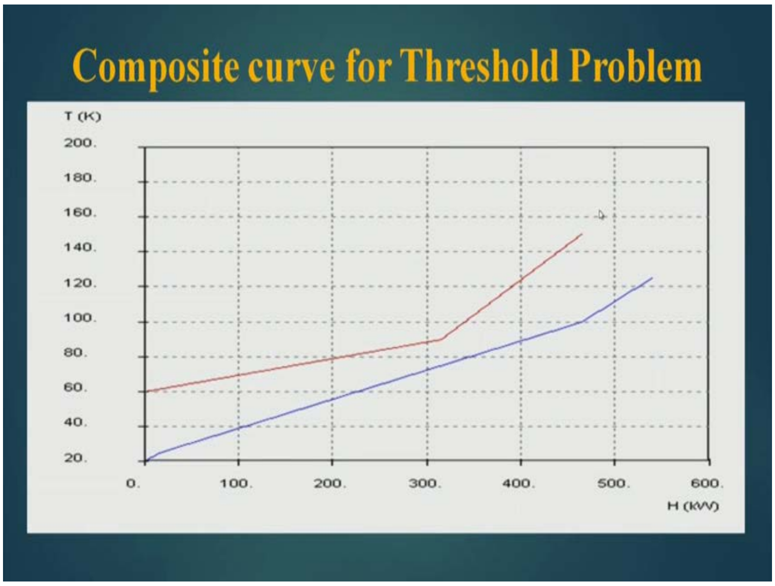

And if you draw and this delta T minimum is 10 degree, it is, have no cold utility requirement, 0 cold utility requirement, but have some hot utility requirement.

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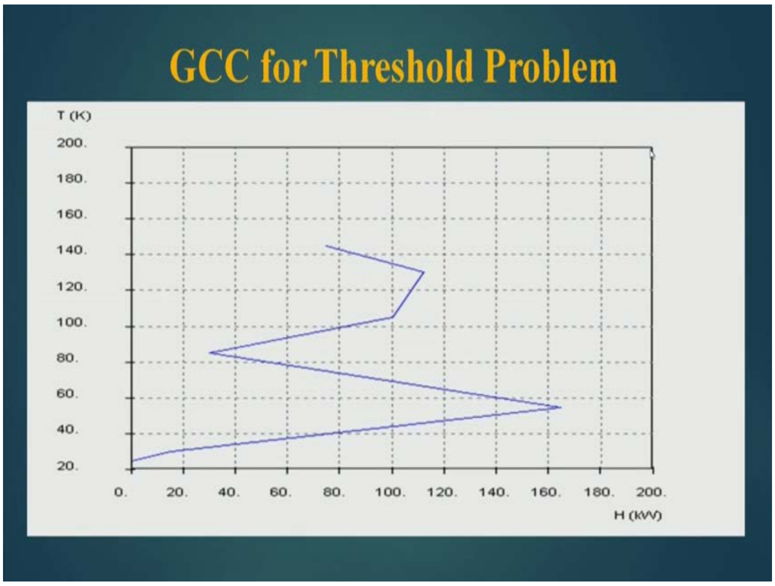

So, if you plot the GCC for this, the GCC look like this and obviously, this is process to process and this is process to process.

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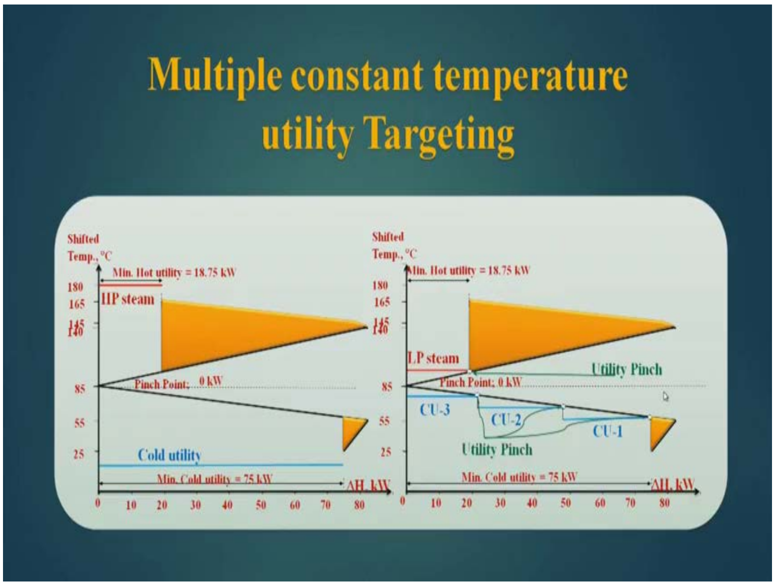

Now, multiple constant temperature utility targeting. I have already told you that GCC helps me, to select multiple utilities when I say multiple hot utility, it means the utilities more than number 1, more than 1 and they are at different temperatures. Now, if you take this GCC, this orange portion shows process to process heat transfer, this also shows process to process heat transfer, that means this is giving heat to the underneath. So, this is process to process heat transfer from here to here, this is heating this lower part, this is process to process heat transfer.

Now, from here to here it requires it because it temperature is increasing, so I have to heat it using a hot utility, So, I can place a hot utility here, which is more than the highest temperature of this GCC and then hot utility requirement will be 18.75. Similarly, cold utility can be placed delta T minimum below this point so that, the heat available here is push to the cold utility, for the, to satisfy the process condition. For this purpose, I can use a HP steam, high pressure steam I can use and I can use a cold utility here, which at lower temperature than this. This is perfectly satisfy the process conditions and the system will perfectly operate, but the question is, this system is operating at what cost? Can I decrease the cost of the system. Specially, the operating cost of the system, the answer is yes, we can decrease it by using alternative hot utilities.

Now, if I put a LP steam here then it will also satisfy the upper pinch area, if I am putting a HP steam here heat will come from this temperature to this temperature, from this temperature to this temperature. So, delta T availability is very high which is not required and this HP steam, that is high pressure steam is at higher temperature and hence, its per cost k g will be higher than the LP steam which at low temperature. Even if I put LP steam here, it will satisfy my, this heating because at this point the temperature difference is delta minimum.

And at this point the temperature difference is delta T minimum more than, delta T minimum. Hence this LP steam is also satisfy the heat demand, that means it will heat up this steam from this temperature to this temperature, but its cost will be far less than the high temperature because it temperature is lower. So, by selecting a LP steam for heating the upper part of the GCC, is a better proposition in terms of cost. Similarly, let us analyze the lower part of the GCC now, I can put here three steams. Cooling steam 1, to cool from this to this, that is the heat from this to this, will go this, cooling utility 2 from this point to this. Cooling utility 3, from this point to this, step point. As these cooling utilities are horizontal in nature that means, I am generating steam here because the steam temperature at the certain pressure will be constant and this is not a specific heat.

The heat is not sensible transfer, this is latent heat transfer, but if I use three utilities, this utility temperature is more, this temperature is more than this and this temperature is more than this. If we compare the cold utility, that is at a lower temperature and hence the, when the temperature of the cold utility is increases, its cost decreases. So, by taking a arrangement like this, what I have done, I have reduces the operating cost of the heat exchanger network, by suggesting alternate utilities.

But one thing we have keep in mind, more is the number of hot and cold utilities, we employ in the system, the system design becomes critical and in many cases the overall area of the heat exchange network will increase. So, we will cut down the cost in terms of operating, but at the same time we may complicate the heat exchanger network and have to provide more area of this purpose, so the cost increases.

So, that is trade up between these two that, how many number of cold and hot utilities I should use, that gives me multiple utility. And what is the complexity we get, so overall analysis in terms of cost will give a answer to such a problem. Now, when we use hot utilities like this LP steam and different cold utilities, we create utility pinch. We know that, process as got as single pinch which is called a process pinch and when we use multiple utilities, we create the multiple pinches.

So, number of pinches in the problem increases, when I said number of pinch points that is, process pinch plus utility pinches, they increase. And once the increase, we will see that they also offer some problem in the design. So, here this is the utility pinch, this is the also utility pinch, this is also utility pinch, this is also utility pinch, so we have four utility pinches in this problem.

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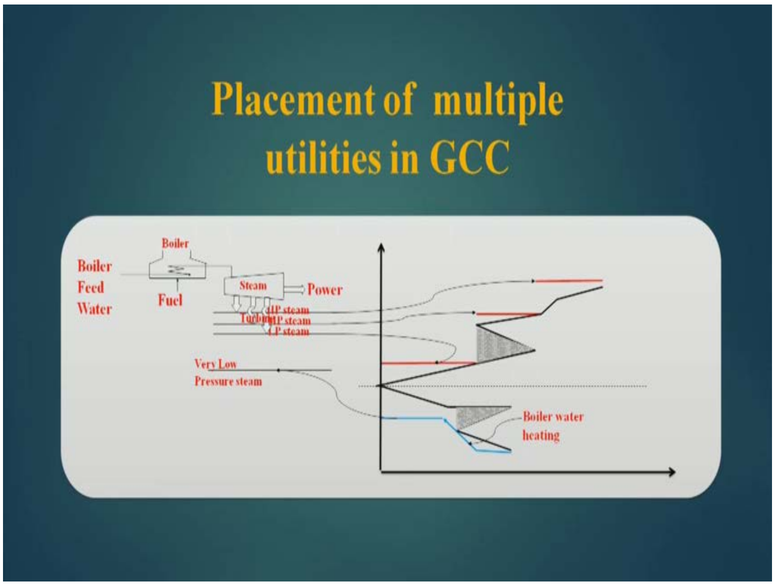

Now, we have seen that by using multiple utilities, we can bring down the utility cost, but in actual practice, how this will happen. To show this, we have shown a boiler here and its steam to power generator here, which provides steam at three pressures. One is HP steam and other is the MP steam and third is LP steam, so three steams are available. HP steam at a highest temperature, MP steam at the medium temperature, LP steam at the lower temperature. So, we have to fit these three steams into this, so let us see how. We are putting up the HP steam with it at the highest temperature here, to heat a part of this curve. And then MP steam from heating from here to this point and then LP steam from heating from this point to this point.

So, what is happening this is the area in which is the process to process heating, this is the satisfied area, so I do not have to bother for this. The steam from here to here to heat to this point and the steam from here to heated to this point. For this heating this, LP steam is sufficient, so heating of steam from this point to this point can be done by this LP steam. Then heating is require from this point to this point, I am using MP steam here and from heating from this point to this point, I am using the HP steam. I can also use HP steam from here to here directly, but the delta T values if I use this HP steam here, the delta T values will be very high, which is not advisable.

So, by using three levels of stream, steam which is coming out from steam turbine, I can satisfy this GCC. So, the upper part of the GCC is now satisfied now, let us see how to do, satisfy the lower part of it. So, the heat is available for this point to this point, so this is the value of heat is available and for this purpose from this, to this heat available. Here this is process to process heating, so I do not have to bother for this.

Now, what I am doing, I am taking a cooling water from this point to this point, and then heating the cooling water to a temperature, boiling temperature and then generating steam for this much of amount. So, this generation of steam takes place while cooling the, while cooling this steam from this point to this point and from this point to this point.

So, a very low steam is not generator due to this so I have raise a very low pressure steam and this steam can be now sold out into the market. If possible or it can be consumed in some other part of the industry, this type of arrangement decreases the utility cost considerably. And thus, the total operating cost of the heat exchanger network decreases.

Now, this heat exchanger network has got two part, one part is the fixed cost and other part is the operating cost. So, we will attack on these two parts and we will try to decrease the fixed part, as well as the operating part, by using a GCC and converting the utilities in to multiple utilities, we can decrease the operating part of the heat exchanger network. That is operating cost of the heat exchanger network, though it will lead to a little bit of more complication.

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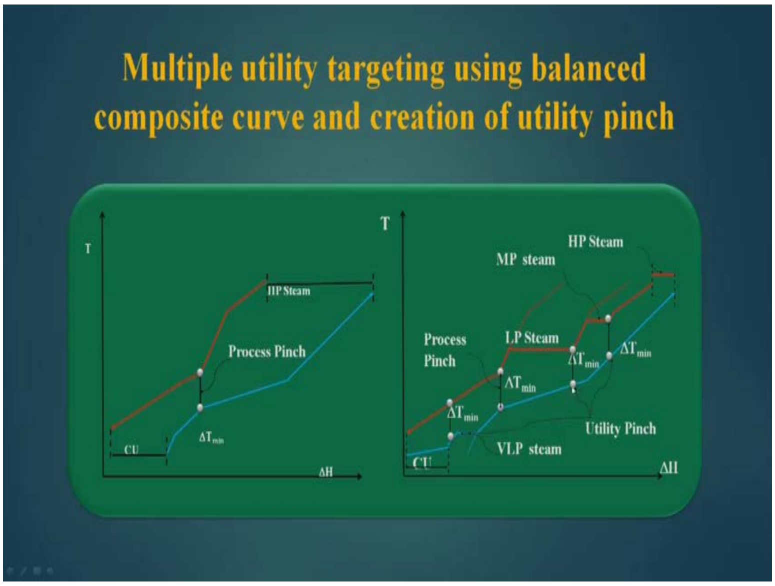

Now, suppose we will see now the multiple utility targeting using balanced composite curve and creation of utility pinches. Now, this is the composite hot curve and this is the composite cold curve. Here the HP steam is being used and here the cooling water is used and we have process pinch here. Now, when we use LP steam, HP steam and create very low pressure steam then how this hot utility hot composite curve and cold composite curve changes, this shows it.

This is a balance composite curve, in a balanced composite curve hot utility steams and cold utility steams are plotted on the composite curve and here you will see that, the hot utility requirement and cold utility requirement is 0, in a balanced composite curve, because the hot utility steams and the cold utility steams are already included into this composite curve. Now, here we see that here LP steam is being is used for heating.

So, this curve shifted to this point and then we are using MP steam and further shifts to this point and then here we are using HP steam. Here we are generating very low pressure steam here and then this is heating part of the cold utility. So, here we find a lot of pinch points, at this point there is a pinch point delta T minimum, this again gives you a pinch point, which are utility pinch.

This is the process pinch, this is a utility pinch, this is a utility pinch and this is a utility pinch. So, we see three utility pinches and one process pinch in this design. By introducing utility pinches the design becomes somewhat complicated. This will know when, we will deal with the design of heat exchanger network for more than one pinch.

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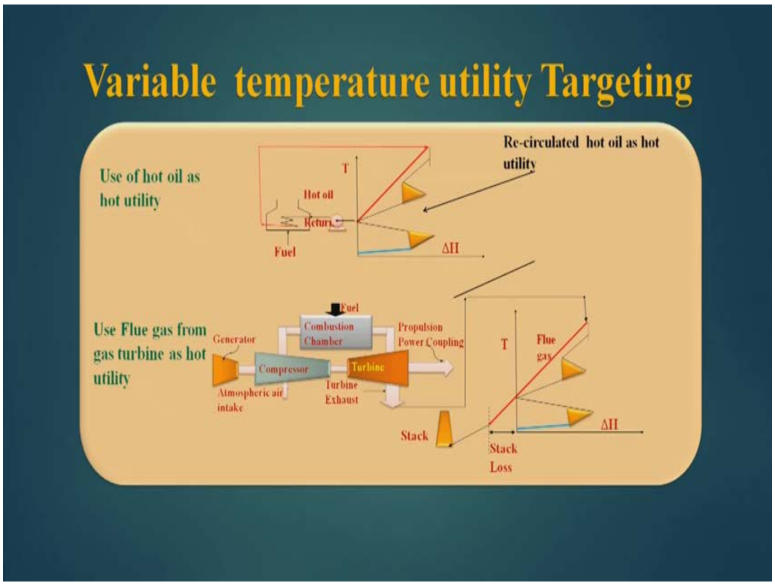

Now, in the earlier problem, we have taken hot utilities which are, which is steam and steam condense at a certain temperature, but if I want to take variable temperature utilities. This variable temperature utilities, gives sensible heat and hence it temperature decreases. Once such variable temperature utility is hot oil now, this is a, here is the heating system where we are burning oil. The oil is heated up and is send to this position where, it gives heat to the steam which require it. So, this is the hot utility and while giving it to temperature drops down.

And here I get the return oil and this return oil is then heated up, pumped to this furnace which heats up the oil to a certain temperature and then it recycle bake here. And then gives heat from this point to this point to satisfy, this area of the GCC, here this is the process to process heat transfer. So, from here to here heat is require and from here to here, the heat is required. Similarly, I am using a cold steam here, whose temperature is rising when I am supplying heat from this point to this point, to this cold utility. So, when I am using a utility temperature is dropping down, the satisfaction, while satisfy the GCC in this manner.

A second example will be the use of flue gases from the gas turbine as hot utility. Now, this shows a gas turbine arrangement, here there is a generator which is, this is a compression and this is a turbine. So, we take atmospheric air, we compress it, we pass it to compression camber, we add a fuel to this combustion chamber, here the combustion takes place. So, the heat temperature of the air increases due to the fuel combustion and that is send to the turbine and this turbine moves, this swapped and the swapped goes to the compression. And generator, it generates the electricity and hot exhaust gas, this is which is available in the bottom of the turbine is used as a hot utility.

So, the inlet temperature, the outlet temperature of this short turbine gas will be more than this temperature. So, this is the fuel gas, flue gas and this part of the flue gas gives heat to, this part of the GCC and satisfied it completely. Then this flue gas goes to a chimney and is used as a exhaust. So, with this flue gas this much amount of heat goes to the chimney, this much amount of gas goes to the chimney. So, during the computation the optimization takes place that how this decrease this. So, we will see that if this temperature is higher then less loss in the stack takes place and the temperature is lower, more loss in terms of stack loss takes place, Here, I am using a cooling water for cooling purpose, so we have seen two variable temperature utilities and how to use these utilities, to satisfy the upper part of the GCC. So, we have until now it is very clear that GCC is useful in placement of hot utilities and cold utilities.

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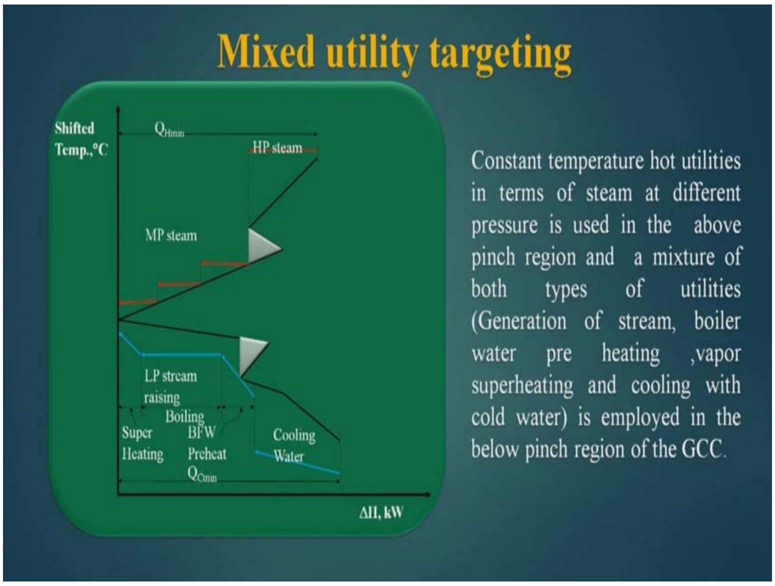

This shows mixed utility, here I am using HP steam, this is MP steam and this is steam at two different levels, so multiple stream, steam can be used to satisfy this GCC. Here also, I am using cooling water to cool down from this point to this point and then taking the water heating it up then generating the LP stream, steam and then super heating at this point.

Basically, I will super heat when I will like to generate electricity out of it, in this zone, the boiling is taking place, this zone is used to heat up the liquid to the boiling point. So, second active heating taking place here, boiling taking place and here, super heating of the steam taking place. And this area we are using cooling water for cooling, from this point to this point. So, we are using mixed utility for the GCC.

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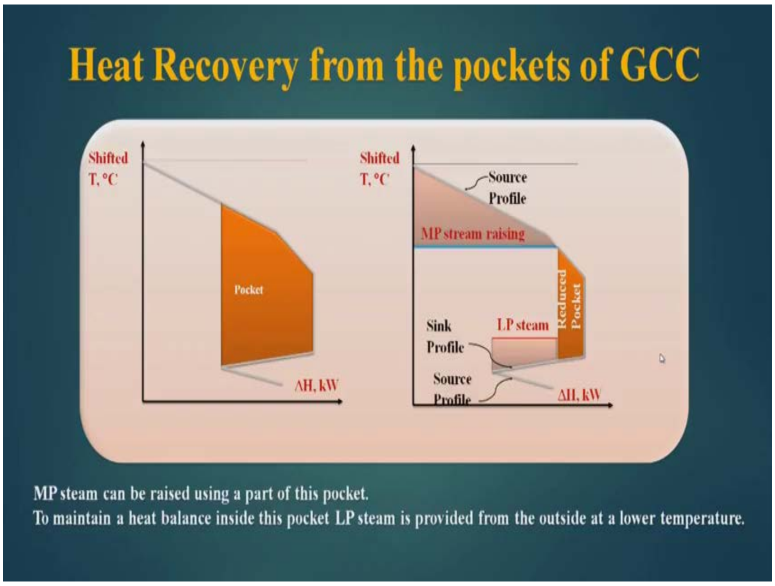

Now, here we will see that, if it is process to process pocket available, can I take heat out of the process to process pocket? The main reason for taking out heat from this process to process pocket is, here the driving force, there is a large driving force available here. And this driving force can be used, for some better work, because at from this temperature to this temperature, the heat is being transfers large driving force.

Can I use this driving force some other purpose? I can substitute some other hot utility for this job that means, the cold steam from here to here is being heated up by the hot steam from here to here. So, that is large driving force available, let us see how do use it, this is the pocket it shows process to process heat exchange. Now, if I raise MP stream here, that means I take heat from this portion of the GCC and create a MP stream here. And then put a LP stream here to heat from this point to this point and the heat release from this point to this point, to take place on a cold water. So, in this point this pocket is reduced to this pocket and I am able to save a temperature differential from this to this. Because to heat these streams I do not need such a large temperature differential, with this small temperature differential I can heat this. So a lot of saving of temperature difference or the driving force can take place, by utilizing the pockets like this.

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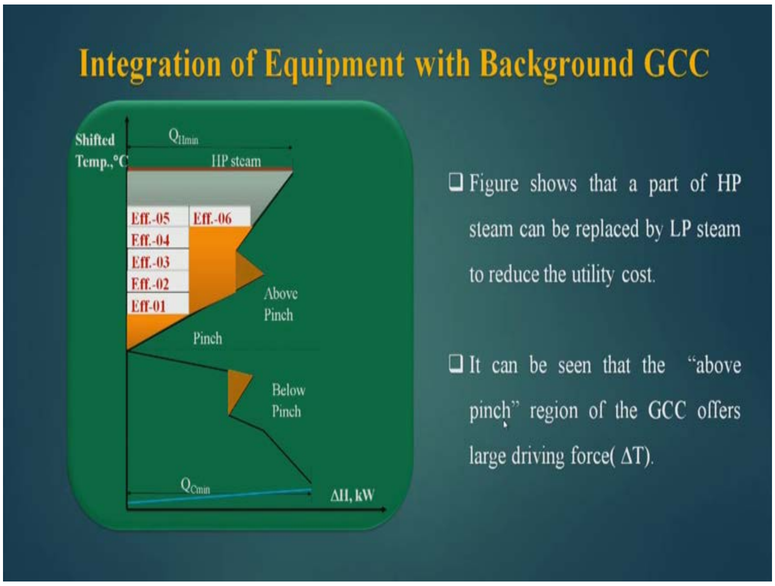

Now, I have told you that, the heat exchanger networks cost are in divided into two parts. The operating cost as well as the fixed cost and then attempts should be taken to decrease both the cost and this example, what we are doing. We are pushing of the HP steam to head, heat a evaporator and the exhaust of the evaporator is used for heating up the other part of the GCC. And in this manner, the operating cost of the evaporator in terms of life steam becomes almost 0.

The method is says that, this is the GCC, this is a pocket where process to process heat transfer is taking place. And this is also a pocket where, process to process heat transfer is taking place and this is above the pinch, for below the pinch we are using Qc minimum, this is cold utility. For the above pinch, we are supplying HP steam here and then impending a multiple effective operator here. The multiple evaporators, 5th number effects and 6 number effect is heated by the HP stream, from this point to this point and from this part to this part, is used to heat up this.

The streams available from this part to this part and the from this part to this part of the HP steam, goes to be effect number 5, to effect number 6. And outlet of the effect number 6 is heating up, this part to this part of the GCC curve and from this part to this part of the GCC curve. Then the outlets stream of effect number 5 goes to 4 then 4 goes to 3, 3 goes to 2, 2 goes to 1 and the outlet stream or outlet vapor of effect 1 is heating up from here to here. So, that is two way to decrease the operating condition.

One way is to use multiple steam, that is HP steam, MP steam, LP steam or very low pressure steam or impending an equipment, that integrating a equipment here, like here we have integrated a multiple effect evaporator system into this. So, this almost runs free of cost, so we get a benefit that by integrating a equipment, the overall operating cost of the heat exchanger network for the GCC, as well as the, that integrated equipment comes down.

Thank you.