Process Integration
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Module - 3
Building Blocks of PINCH Technology
Lecture - 4
Hot and Cold Composite Curves and "The Pinch"

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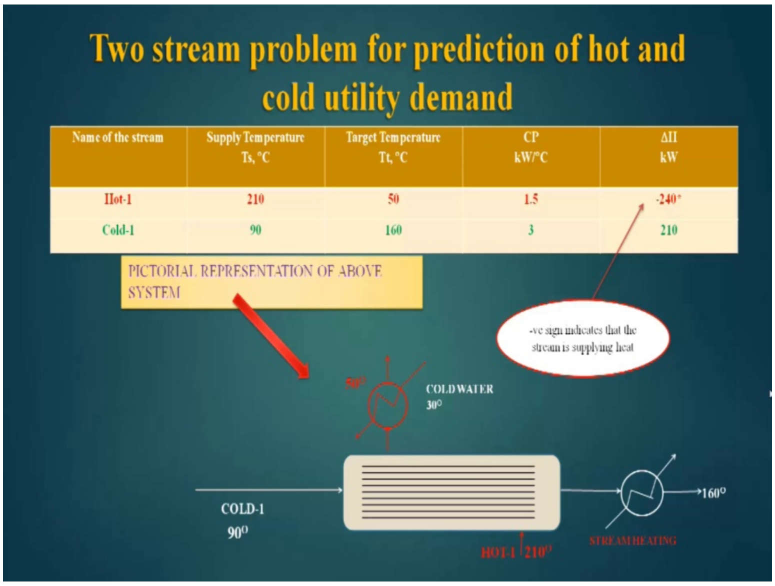

Welcome to the lecture series on Process Integration. This is module number 3, lecture number 4. And topic of the lecture is hot and cold composite curves and the pinch. Up till now, we have seen how to create a hot composite curve, how to create a cold composite curve. Now, we will extract some useful information by plotting the hot and cold composite curves simultaneously, and we will find out what is the requirement of the hot utility as well as cold utility from these curves. Further, we will see that what more information this curves communicate to us. To start with, we will take a two-stream problem for the prediction of hot and cold utility demand.

We take two stream problems one hot and one cold, the supply temperature of the hot stream is 210 degree centigrade and the target temperature is 50 degree centigrade, whereas for the cold stream this is 90 degree centigrade and 160 degree centigrade. Below shows a pictorial view of this streams, the cold stream is entering at 90 degree centigrade to the heat exchanger. And once it comes out, we have used a heater, where we are supplying the hot utility as steam and that heats the cold stream to 160 degree centigrade. Similarly the hot stream enters at 210 degree centigrade from the bottom of the heat exchanger comes out of the heat exchanger and then we are using a cooler to cool it to 50 degree centigrade. In the cooler, we are using cold water as cold utility, which is entering at 30 degree centigrade.

Now, our aim is to find out what is the temperature of the hot stream when it comes out from the exchanger and what is the temperature of the cold stream when it comes out from the exchanger and what is the demand of hot utility and cold utility? Let us see how to compute the requirement of hot and cold utility demands as a function of delta T minimum for the problem, we have discussed earlier now.

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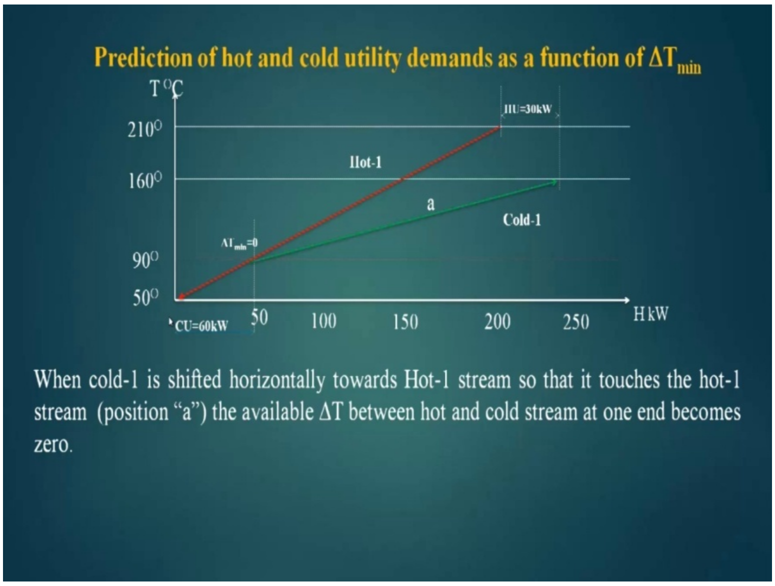

For this purpose, let us plot the hot stream and cold stream in a T-H diagram denoted by hot-1 and cold-1. Now what do we can do we can shift this cold stream horizontally to touch the hot stream. At this position, one end of the cold stream is touching the hot stream, where delta T minimum is equal to 0. At this position, the hot utility demand which is the horizontal distance between this and this is 30 kW and the cold utility demand which is the horizontal distance between this end of the cold stream and this end of the hot stream is 60 kW. So, at delta T minimum equal to 0; I can say that the hot utility demand is 30 kW and cold utility demand is 60 kW. However, no heat transfer can take place at delta T minimum equal to 0, because area requirement for the heat transfer will be infinite. So, this is a hypothetical case; in actual practice delta T minimum will have some value.

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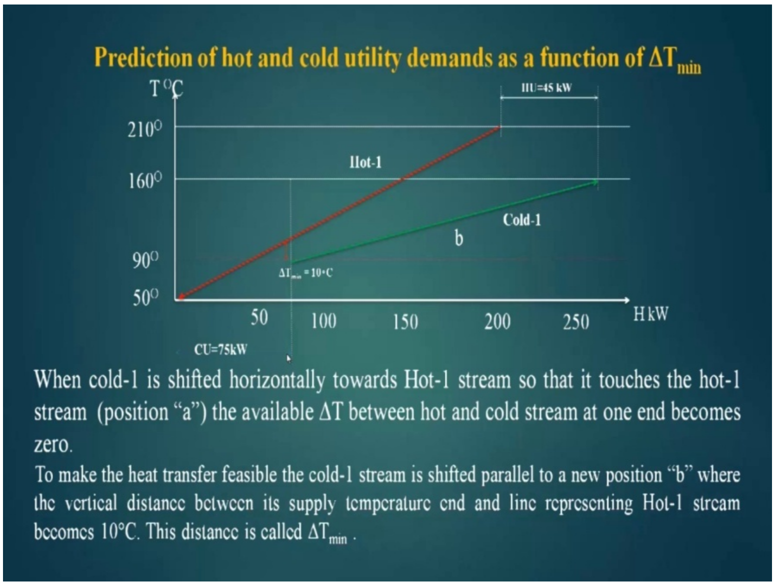

For the problem we have discussed earlier in the last line let us try to find out what is the hot utility demand and what is the cold utility demand when delta T minimum changes for this in the T-H diagram let us plot the hot stream-1 and cold stream-1. Now, let us move the cold stream to a position, where one end of the cold stream touches the hot stream; making T delta T minimum equal to 0. At this position, this end the horizontal distance between this end and this end is 30 kW. This is the hot utility requirement of the system, because the heat from the hot stream-1 will reach up to this position of the cold stream and from this to this position the cold stream will remain unheated. And thus to heat the cold stream from this position to this position, we need external heating; and for this external heating, we have to employee hot utility and the value of the hot utility is 30 kW.

When the cold stream touches the hot stream the delta T minimum becomes equal to 0 and at delta T minimum equal to 0 no heat transfer can take place, because the area requirement for heat transfer in this case is infinite. So, it is a hypothetical case, but for this situation the cold utility requirement is 60 kW which is the distance between from this end of the hot stream to this end of the cold stream. There is no cold stream to cool the hot stream from this point to this point and hence, we have to use an external cold utility to cool the hot stream from say this position to this position and the requirement will be 60 kW. As, I have told you the delta T minimum equal to 0 is a hypothetical situation, we have to provide some delta T minimum value; to convert this problem into a real problem.

Let us say, the delta T minimum is kept at 10 degree centigrade for this purpose the cold stream shift horizontally to a new position called “b”, where the distance between the cold stream and the hot stream is 10 degree this vertical distance is 10 degree which is equal to delta T minimum. Here, we observed that when this cold stream is shifted and delta T minimum is maintained at 10 degree centigrade, the hot utility demand and the cold utility demand changes from the earlier one. Now, the hot utility demand is 55 kW and the cold utility demand is 75 kW; what do we have observed both the hot utility demand and the cold utility demand has increase substantially when we have increase the value of delta T minimum.

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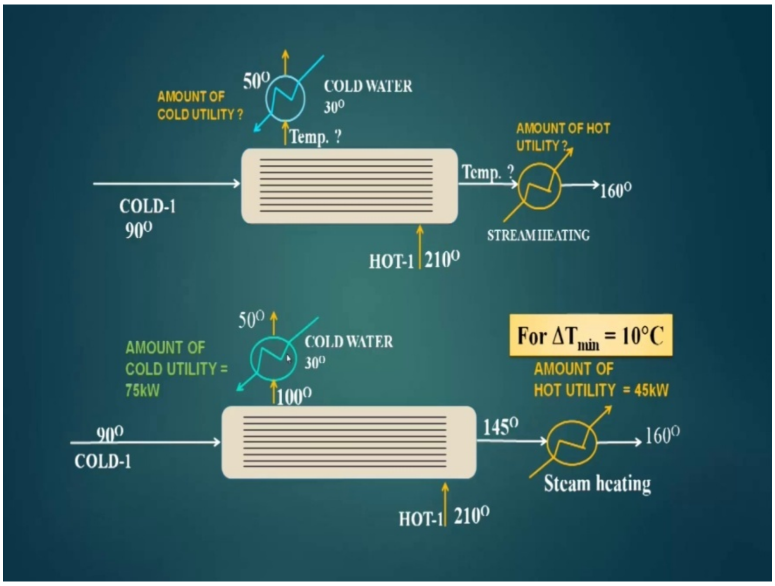

Now, if I translate or convert this information into my p f d; I can find out the required temperatures and I can answer the question given in this figure that is what is the amount of cold utility and what is the amount of hot utility? The temperatures for delta T minimum equal to 10 degree centigrade. Here the cold stream and the picture below; the cold stream is heated from 90 degree centigrade to 145 degree centigrade in the heat exchangers and then it is further heated from 145 degree centigrade to 160 degree centigrade using a steam heater; that means, this heater is heated by this steam and cold stream is being heated and the amount of hot utility required is 45 kW, which we have seen in the hot and cold composite curves, similarly the amount of the cold utility requirement is 75 kW and the hot stream enters into the heat exchanger, at 210 degree centigrade comes out at 100 degree centigrade and then it is further cold by a cooler and in this cooler, external cold water is used for cooling the hot stream from 100 degree centigrade to 50 degree centigrade. So, this is the physical representation.

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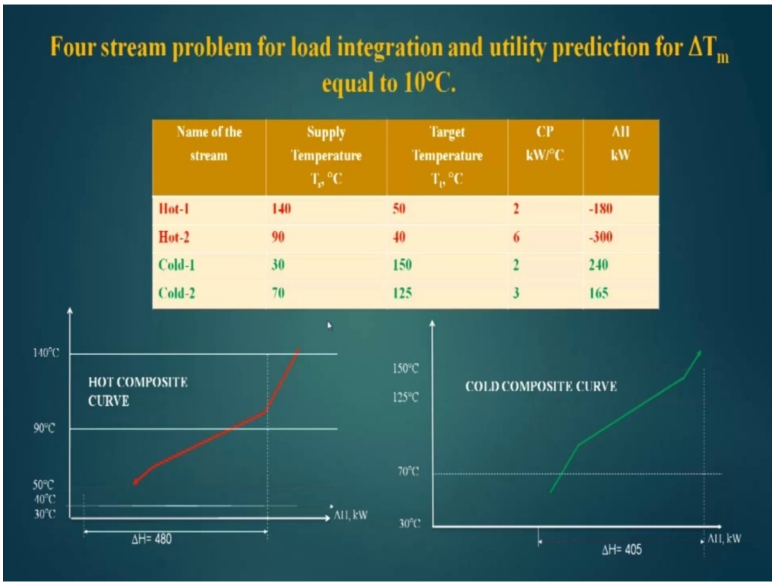

Now, we take a four stream problem for load integration and utility prediction for delta T minimum equal to 10 degree centigrade. Here, we have already fixed the delta T minimum and we will do this using the heat integration principles. That the hot composite curves for this can be drawn as shown below and the cold composite curve is also shown below.

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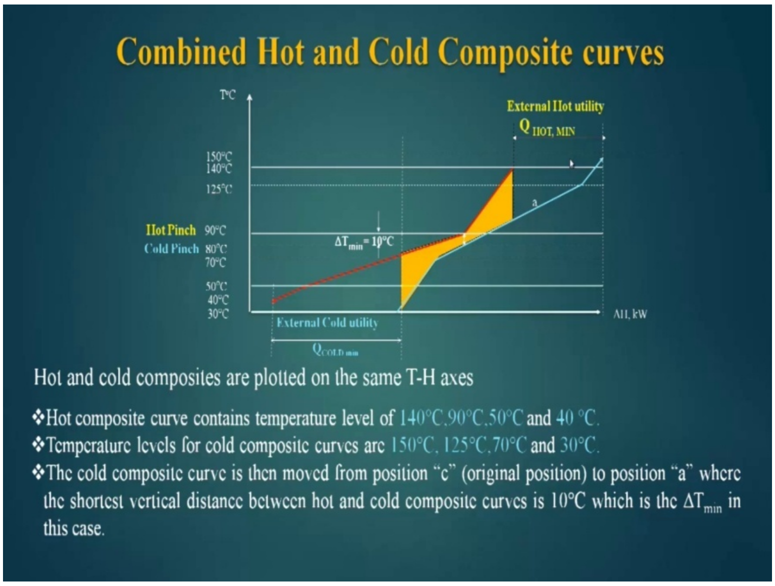

Now, in the T-H diagram we will plot the combined hot and cold composite curves. So, we have now placed both hot and cold composite curves in the T-H diagram. The hot composite curves contain temperature level 140, 90 and 50 degree centigrade and 40 degree centigrade, where as the temperature levels of the cold composite curves are 150, 125, 70 and 30 degree centigrade. Now, I will move the cold composite curves horizontally towards the hot composite curves to maintain the delta T minimum temperature. So, it moves to a new position "b" to a new position "a" and then the area marked by the orange; shows that this is the area, where hot streams will transfer heat to the cold streams. This is the hot stream this is transferring heat to the cold stream. So, hot stream from here to this is transferring heat to the cold stream this from here to here.

This part of the hot stream is not serviced by the cold stream and this part of the cold stream is not serviced by the hot stream. So, from cold stream from here to this position will be heated by an external utility, which is called the hot utility. The hot stream from this point to this point will be cool down by an external cold utility which will be a cold stream. Now, the shortest distance between these two curves is delta T minimum which is 10 degree centigrade. Now, in this case the horizontal distance between this and this is the external hot utility and the horizontal distance between this and this is the external cold utility.

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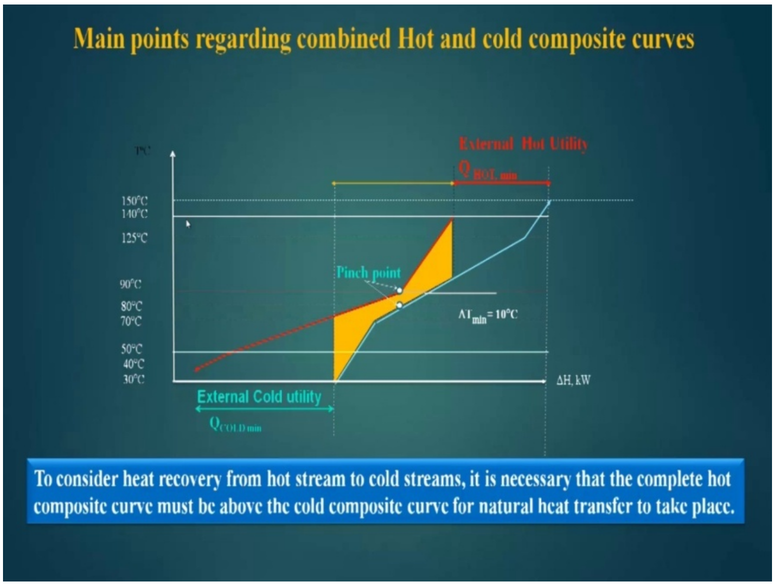

Let us see, now what are the main points regarding combined hot and cold composite curves. We know that, this is a combined hot composite curve; that means, all hot composite curves have been combined into a single fictitious curve, which is a combined hot composite curve. All the cold streams have been combined into this fictitious curve which is a combined cold composite curve.

Now, when I bring together there is point where the distance is minimum and this is the pinch point. Basically, when I say pinch point here there are two points, one end of this vertical line and the other end of this vertical line. So, this is vertical distance is 10 degree centigrade and that is why there are two point one point is called hot pinch and other point is called cold pinch. This is the hot pinch and this is the cold pinch. Now, when these two curves come together they communicate. So, many things the area under this two curves; that means, from this point to this point the area marked by orange colour is the area where internal heat exchange is taking place. This area from here to here it shows the area of external hot utility and this for to this show the external cold utility.

Now, to consider the heat recovery from hot stream to cold stream, it is necessary that the hot composite curves should be above the cold composite curves. If it is so, then only the heat transfer will take place from hot to cold, because hot will be at a higher temperature then the cold and natural heat flow will take place from a hot temperature to a lower temperature.

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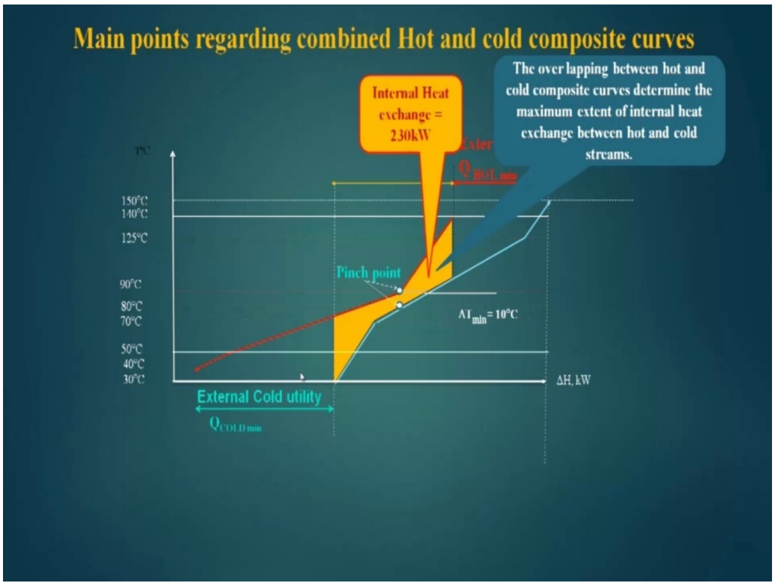

Now, this overlapping I had already told shows the internal heat exchange. Due to this internal heat exchange, heat is remaining into this system hot is giving heat to the cold and cold is being heated up. Obviously, we will like that this heat exchange should be maximum to bring down the operating cost. This is the internal heat exchange and in this case this is 230 kW.

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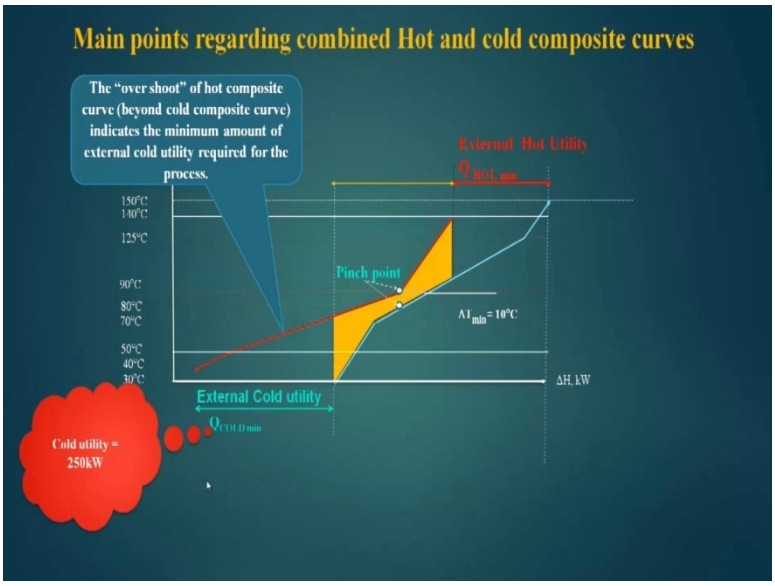

Now, the over shoot of the hot composite curves; this is the overshoot of the hot composite curves beyond the cold composite curves, that is cold composite curve ends here. So, beyond this is the overshoot indicates the minimum amount of external cold utility requirement. So, the horizontally line from this to this shows how much external cold utility is required. Similarly, in this case the cold utility requirement is 250 kW.

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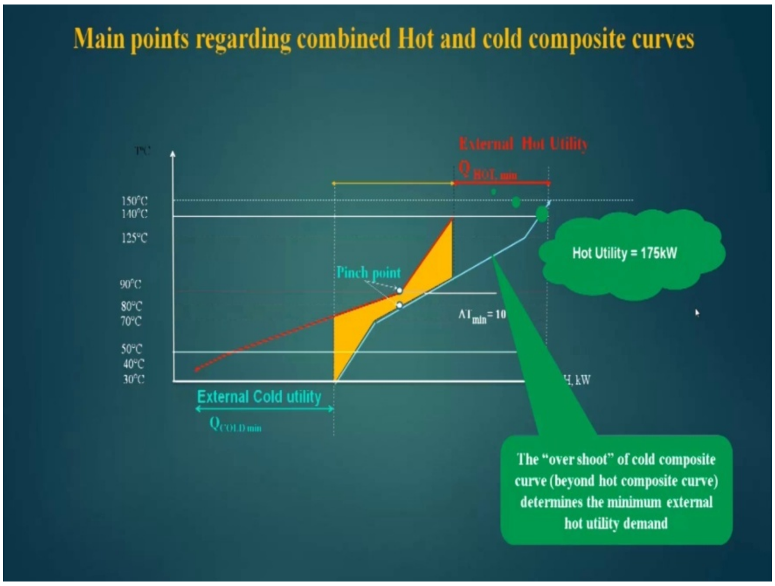

Similarly the over shoot of the cold composite curves beyond the hot composite curves because the hot composite curves end here and this is the over shoot beyond the hot composite curves; determines the minimum external hot utility demand and this horizontal distance shows the amount of hot utility requirement, because this x-axis is a delta H x-axis and in this case the hot utility requirement is 175 kw.

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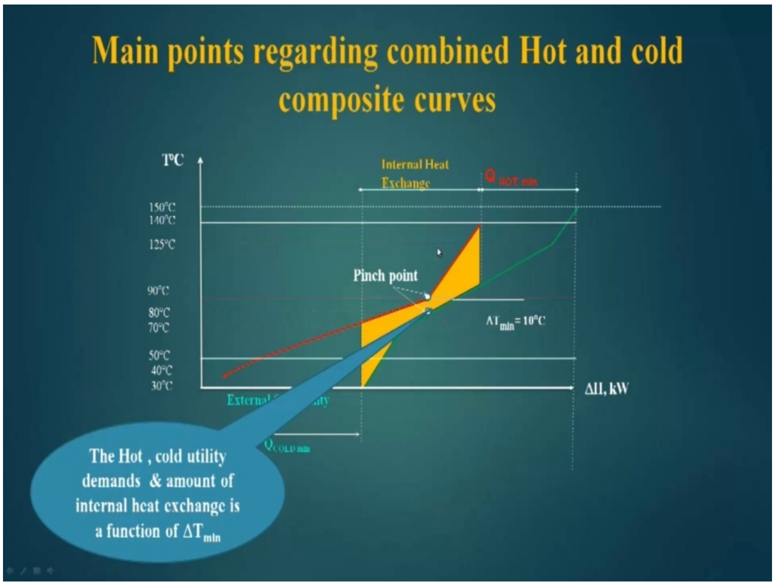

Now, let us see the main points regarding the hot and cold composite curves. Here, this is the pinch point. Now, what do we observed till now that the amount of hot utility requirement, the amount of cold utility requirement and internal the heat exchange is functions of delta T minimum. That means, when I am changing this delta T minimum it is affecting all these three parameters that is internal heat exchange, hot utility requirements and cold utility requirements.

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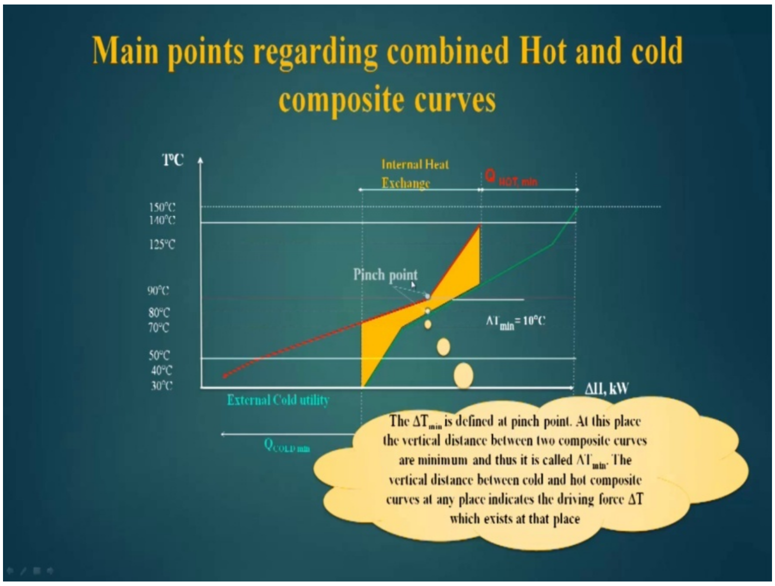

The delta T minimum is defined at pinch point, at this place the vertical distance between the two composite curves are minimum and thus it is called delta T minimum. That means, the delta T available for the heat exchange internal heat exchange is minimum at this pinch point, because the vertical distance between the hot composite curves and cold composite curves is minimum here and that is why this is called delta T minimum.

Now, this was the driving force which is available at this point. Now, you can see that for internal heat exchange the driving force at pinch point is minimum, if delta T minimum is there the heat exchangers which will be created near to the pinch point will have very large area, because delta T minimum is low or lowest. Whereas if you see delta T minimum, here is far more than the pinch point and hence that the heat exchange will be mutually operated in this joule or in this joule, they will have more driving force they will work under more driving force and hence less area. That means, the size of heat exchanges near the pinch point will be large, where as when we go away from the pinch point the size of the heat exchanges will change.

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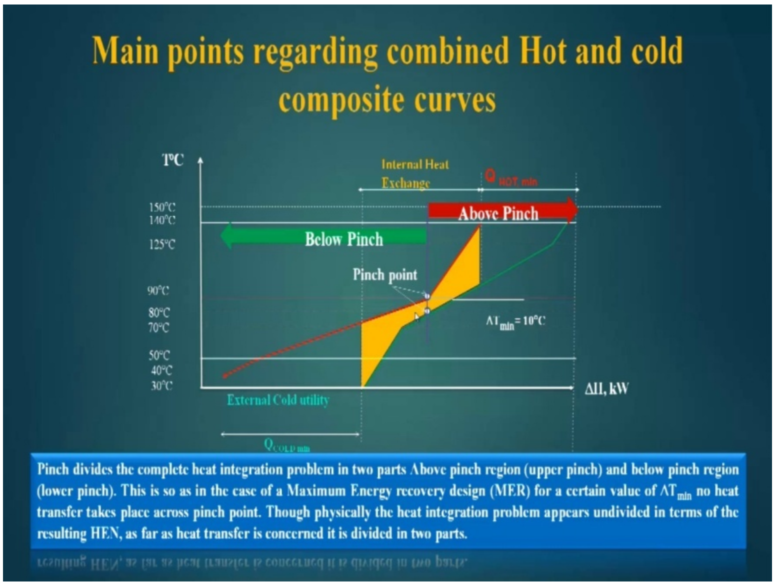

Now, we will see in the future lectures that pinch point divides the problem into two parts. The first part is called above pinch area and this part is called below pinch area. Pinch divides the complete heat integration problem into two parts above pinch and below pinch this is so as, in this case of maximum energy recovery design in an MER design for a certain value of delta T minimum, no heat transfer takes the place through the pinch. Though the heat exchanger network, appears physically as a single network, but if we see from the point of view of heat transfer it is divided into two parts, the above pinch area and the below pinch area.

The above pinch area and there is a thermal equilibrium in this above pinch area and there is a thermal equilibrium in this below pinch area; that means, the cold utility plus and the heat from required by the cold stream from here to here is equal to the heat available with the hot stream. So, it is thermally balance the below pinch area is thermally balance and the above pinch is also thermally balance. The MER design no heat flows to the pinch point and that is why if you see thermally it is a decoupled system. The above pinch has got no thermal relationship with the below pinch area.

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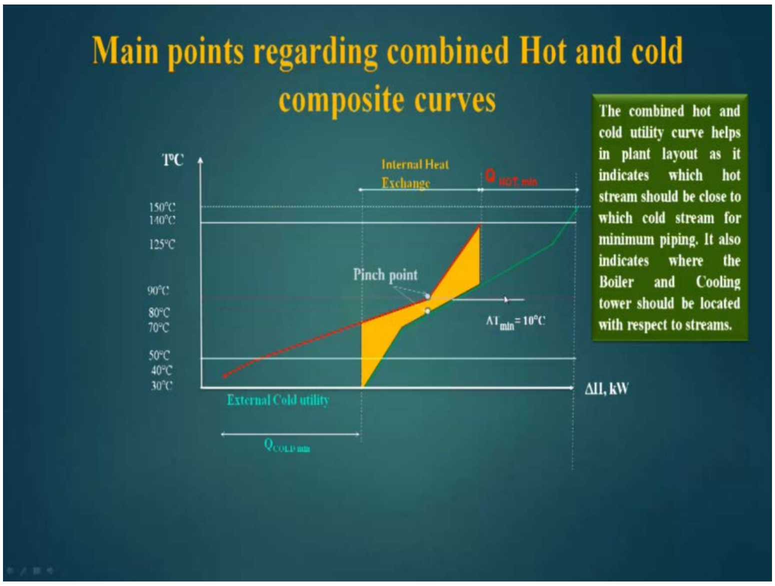

The combined hot and cold utility curves helps in plant layout. Also how now, this is an area where hot utility demand is there and from where the hot utility is coming from the boiler we are getting stream or from the heater we are getting a hot. So, if I have to put a boiler then I will put in this region when I say in this region. These cold streams are in a certain region of the plant and as the hot utility will heat these streams. So, my boiler should be near to these streams. Similarly if I have to put a cooling tower; I have to put in this region, because the cold utility will cool the hot streams which are present from this to this region.

So, my cooling tower will somewhere come into this region, if I consider vertical heat transfer then the hot streams which are available in these reason are giving heat to cold streams of this region. So, the equipment from where these hot streams are coming and the equipment to which cold streams are going they should be near to each other. Similarly, we can argue for this reason also, if based on this principle I put my plant layout, then the piping cost will be minimum.

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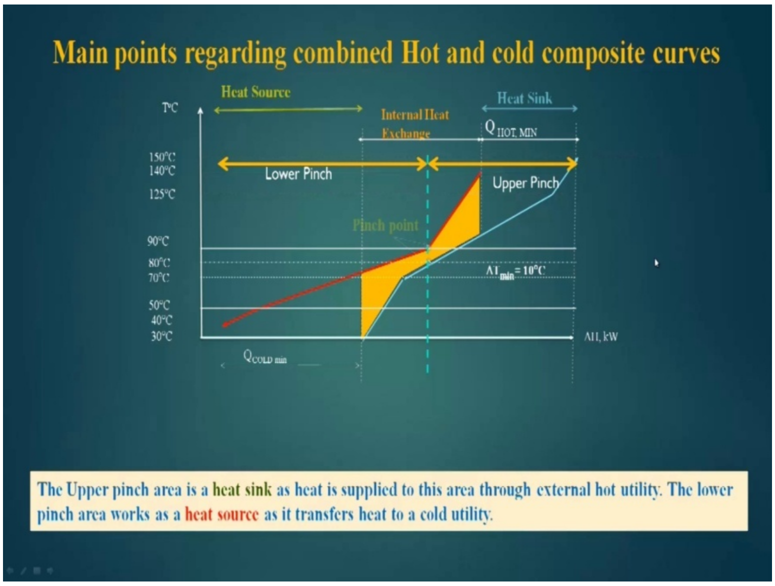

Let us see, some other points regarding the combined hot and cold composite curves. Now as I have told that pinch point divides the combined hot and cold composite curves in two parts; the upper pinch area and the lower pinch area. If you see the upper pinch area which is basically this area; it is a heat sink because heat is coming to the system from outside. So, if this area observes it and the heat which is being pushed out to this area is used to heat this cold streams from this point to this point.

Similarly, the lower pinch area which is this area; it is a heat source because from this system is heat is goes to the cold utility; that means, heat is coming out from the system and hence this area is a heat sink this shows the heat source and this shows the heat sink.

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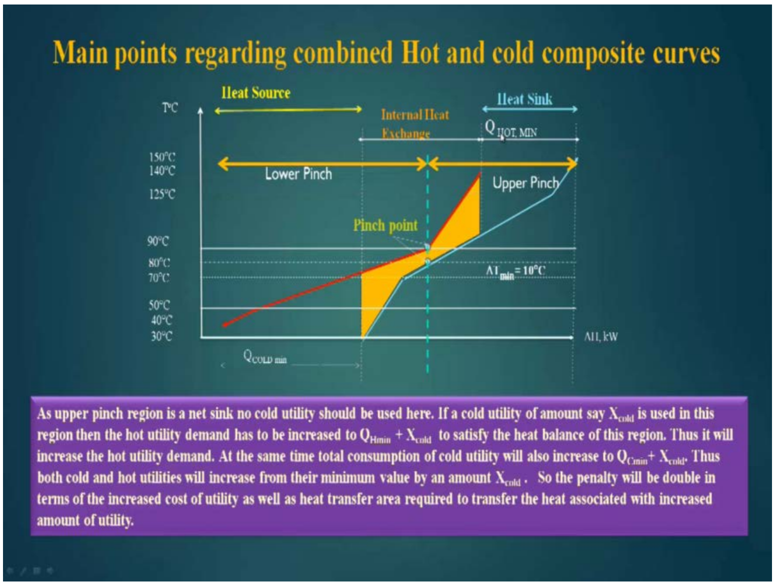

Now, a clearly told that as upper pinch region is a net heat sink no cold utility should be use there. That means, in this area you cannot use cold utility, if I use some amount of cold utility then it will increase the amount of hot utility. Similarly, as this area is a net heat source that is lower pinch area I cannot use hot utility here.

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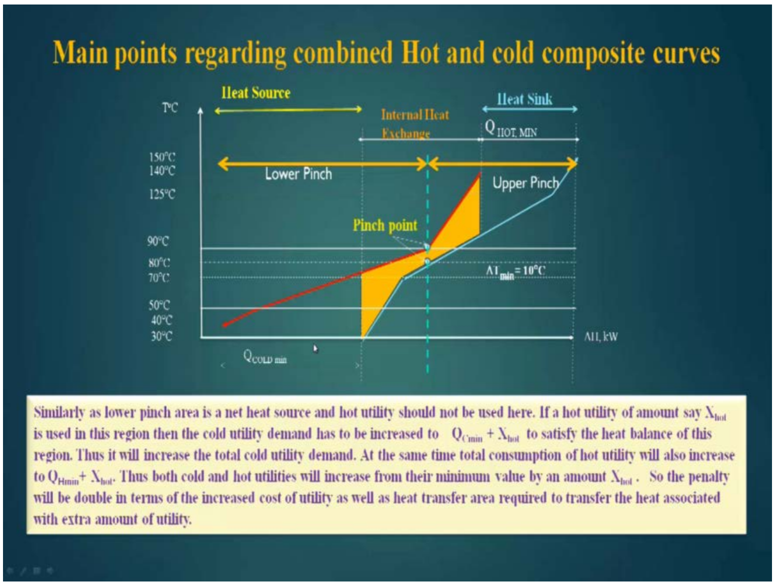

So, this can be shown that, if I add some hot utility here my cold utility demand will increase and hence the operating cost will increase. These you know punishment will be double, because if I am using a cold utility here the amount of hot utility will increase.

So, my operating cost is increasing plus the area which I have to provide to pass this cold utility here will also increase the fixed cost of heat exchanger network.

Similarly, if here I am using a hot utility then the amount of cold utility will increase and also I will be have to use a some way have to provide a heat transfer area to pass on this hot utility and hence the fixed cost will be increased. So, there are two rules in this pinch design that you cannot use cold utility at the upper part and the hot utility at the lower part. The pinch analysis through which we are implementing the process integration is basically a graphical method and hence you just say a lot of graphical representations.

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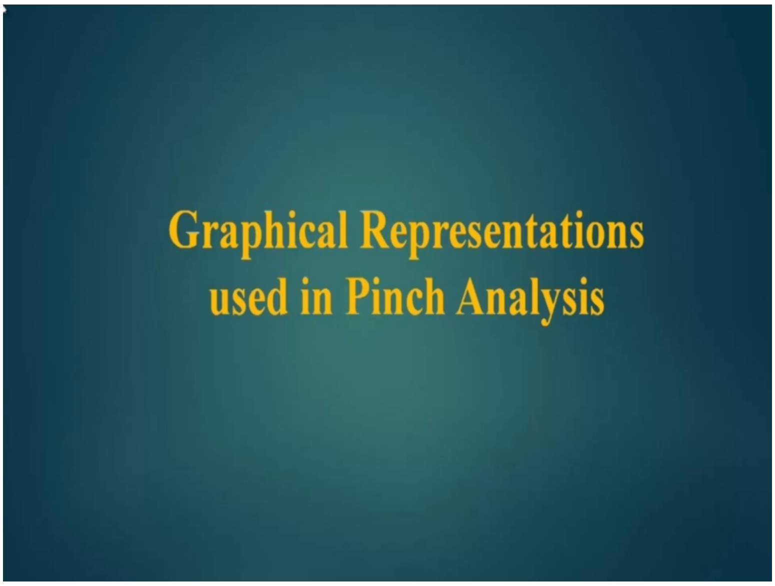

To know the pinch analysis we should know these graphical representations and now we will see that what are the different graphical representations, which are used in pinch analysis.

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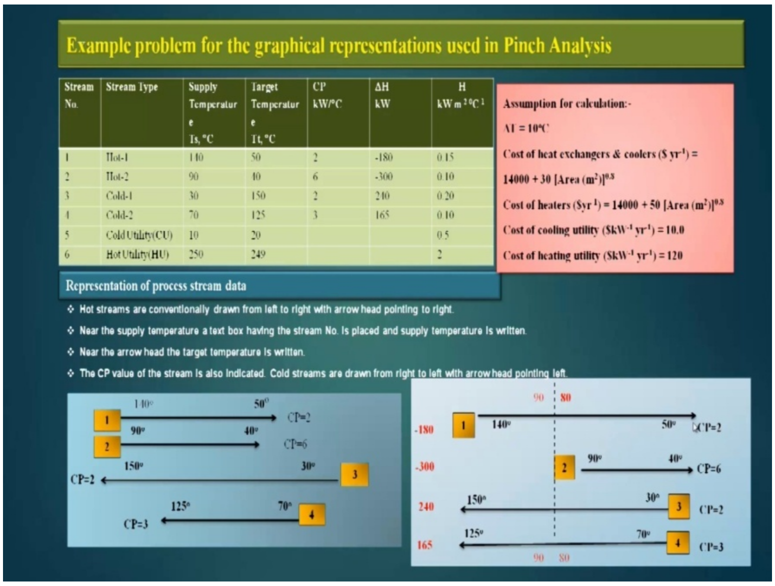

For that, we will take a problem because pinch start with the stream problem; we have taken a stream problem here, where we have taken 2 hot streams, 2 cold streams, 1 hot utility and 1 cold utility. There are some other data which has been taken as delta T minimum. The cost of heat exchanger and coolers cost of heaters, cost of cold utility and cost of hot utility. This is a complete problem through which we can also doing the targeting, but for this present case we may not be using this data completely.

Now, in the pinch there is some representation of process stream data. Hot streams are conventionally drawn from left to right with arrow head pointing to the right. Now, this is number 1 stream is a hot stream it is drawn from left to right and arrow head is pointing to the right; near the supply temperature it takes place pass having a stream number is placed. Here, we are writing out the stream number this is stream number 1, 140 is the starting temperature that is supply temperature of the hot stream and 50 degree is the target temperature of the hot stream.

So, 50 degree is written at the end near the arrow and the CP value of the hot stream is written here, which is CP equal to 2. Similarly, this stream number 2 is written; this starts from here goes up to here. So, arrow is in this direction; in the right direction. This is the supply temperature 90 degree, this is the target temperature and this is the CP value then cold stream start from here and the arrow goes to here.

So, this is the reverse way it is being represented and this is the stream number. This is the supply temperature and this is the target temperature. Similarly, the cold stream 4; is this is the supply temperature, this is the target temperature and this is also drawn from right to left. Now, here we will see that is another representation grid representation this is plotted from left to right hot streams, from left to right cold stream and from right to left and this is a sorted line, which shows the pinch. The 90 degree shows the hot pinch and 80 degree shows the cold pinch and these are the CP values.

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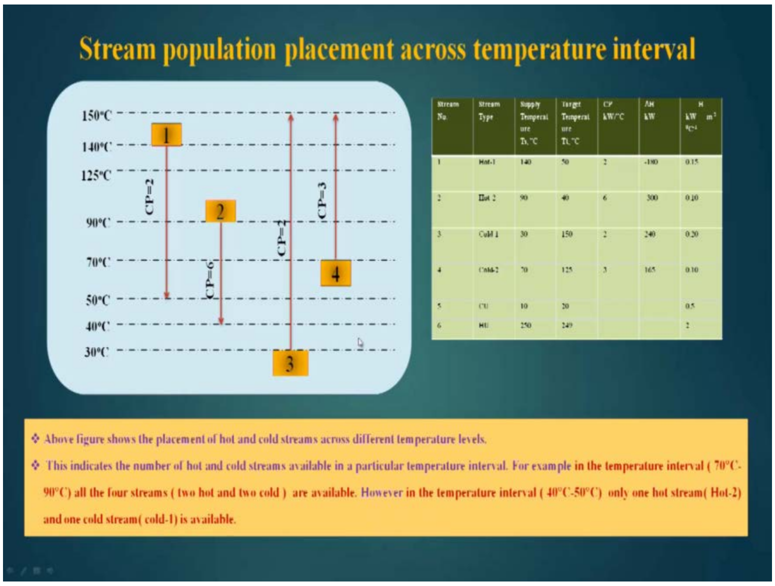

Stream No.	Stream Type	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH kW	H kW m⁻² °C⁻¹
1	Hot-1	140	50	2	-180	0.15
2	Hot 2	90	40	6	300	0.10
3	Cold 1	30	150	2	240	0.20
4	Cold-2	70	125	3	165	0.10
5	CU	10	20			0.5
6	HU	250	249			2

Now, we are drawing the temperature levels; because the hot and cold streams we will have different temperature level and based on this we have plotted this temperature level. These are the combined temperature levels of hot streams and cold streams. The hot stream-1 has got two temperature level that is 140 and another 50 and these hot two has got two temperature level 90 and 40 this cold stream one has got two temperature level 30 and 150 cold stream to is 70 and 125. Now, once we have plotted this temperature levels we can fix up this streams.

So, the hot stream starts from 140 degree centigrade it goes up to 50 degree centigrade and it is represented like this. Now, the hot stream-2 is represent like this; hot stream-3 like this and hot stream-4 like this. The CP values are written here. Stream numbers are written. So, its shows that in this temperature intervals only two code spins are working; in this temperature interval between 140 and 125 one hot stream is working and two cold streams are working in this temperature 90 to 125 one hot stream is working and two cold streams are working and in temperature interval 70 to 90 one hot streams, second hot streams and two cold streams are working. In this temperature interval, two hot streams are working and one cold streams are working and in this temperature 40 to 50 one hot stream is working and one cold stream is working and from 40 to 30 degree centigrade only one cold stream is working.

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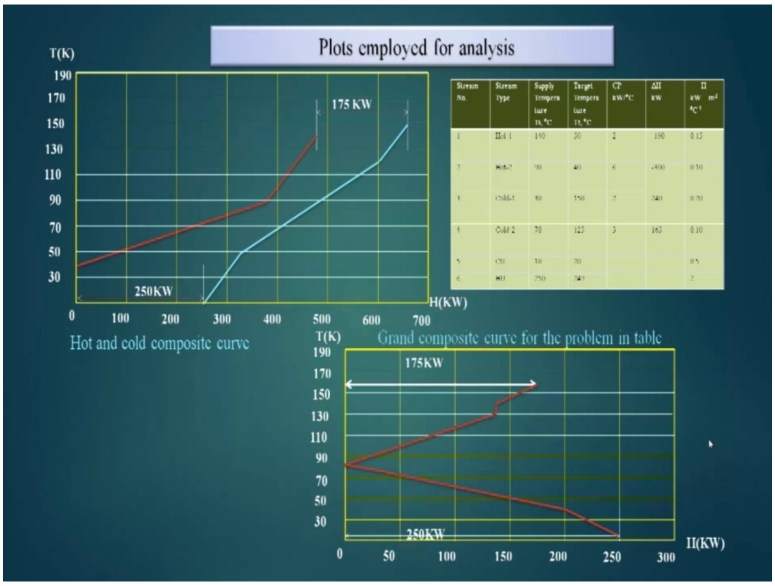

Now, this plot, we know this is shows the hot composite curve and this shows the cold composite curve. For this problem, this shows you the hot utility requirement and this shows you the cold utility requirement; then there is grand composite curve. The grand composite curve looks like this; we will explain it later on what is the grand composite curves and how this is plotted. First you remember this, looks like this from this grand composite curve also we can find out what is the hot utility requirement and cold utility requirement.

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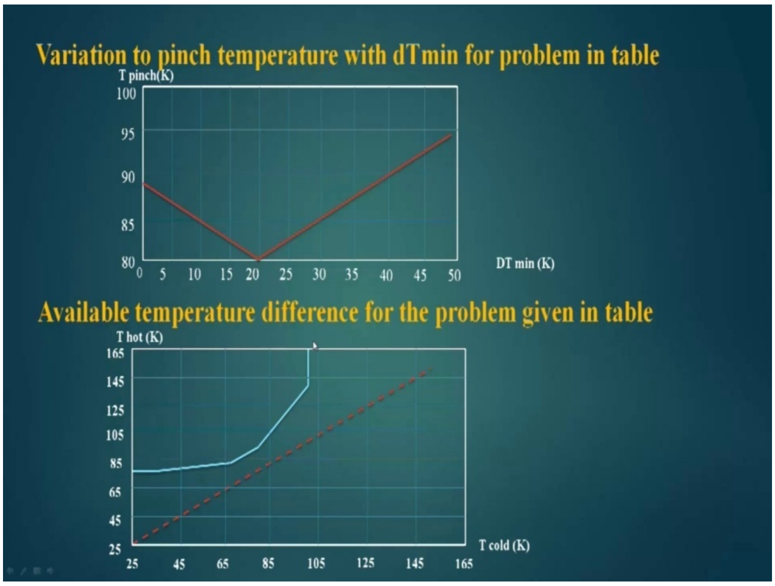

This is a variation of pinch temperature with delta T minimum. So, this is a curve which shows that if delta T minimum is changing; then how the pinch temperature will change. Now, this shows you the temperature difference for problem given in the table. That means, what is the different between combined hot stream and combined cold stream and what is the temperature different available for this purpose in the total problem is shown by this. So, this is measured from here to this.

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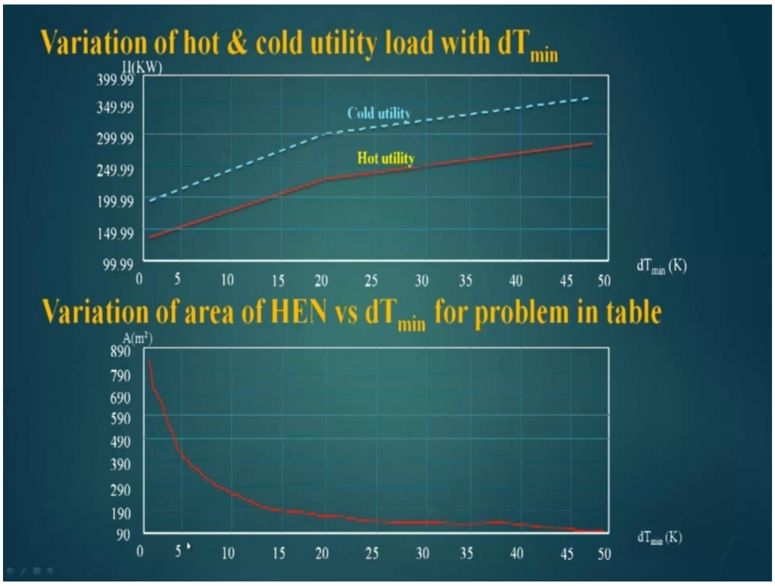

Now, this is a plot, which shows that how cold utility and hot utility are changing. The amount of cold utility and hot utility are changing with delta T minimum. That means, when delta T minimum is changes the amount of cold utility and hot utility changes as well as the amount of heat interchange also changes. This shows you the variation of area of the HEN as a function of delta T minimum. So, when the delta T minimum is increasing the area of the heat exchanger network decreases and when the delta T minimum decreases the area of the heat exchanger network increases.

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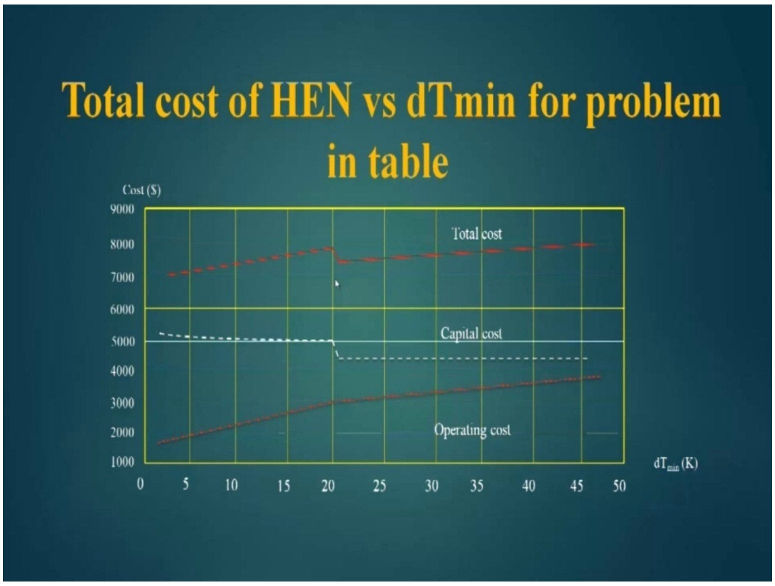

Similarly, you can have cost when delta T minimum changes; this is the operating cost how the operating cost is changing when delta T minimum increases, the operating cost increases and this is the total cost and this is the operating cost with delta T minimum. This is the capital cost that is fixed cost of the as a function of delta T minimum. This is the overall cost that is tat total involved cost, which is a summation of the part of capital cost and operating cost. This shows the total involved cost as the function of delta T minimum.

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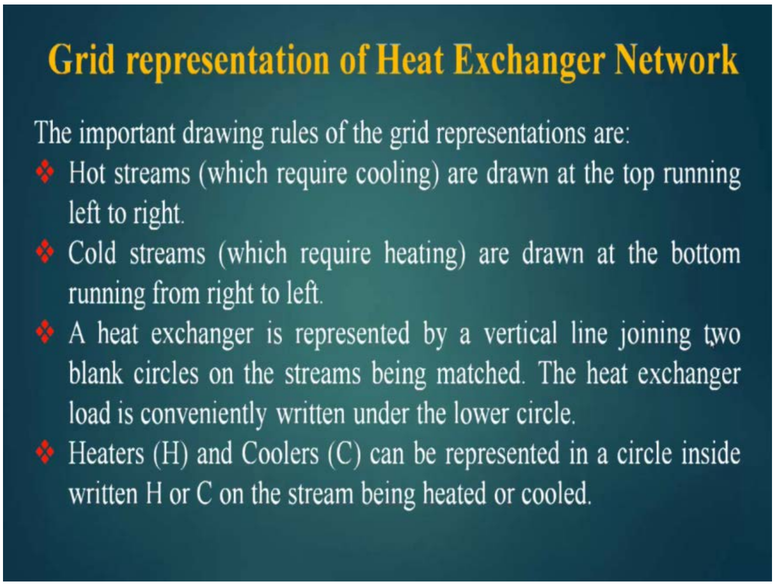

Now, to conclude the grid representation of heat exchanger network is shown below. The hot stream are drawn at the top running left to right cold stream are drawn at the bottom running to right to left at heat exchanger is represented by a vertical line joining two blank circles on the stream being matched. The heaters and coolers are represented by H and C inside a circle.

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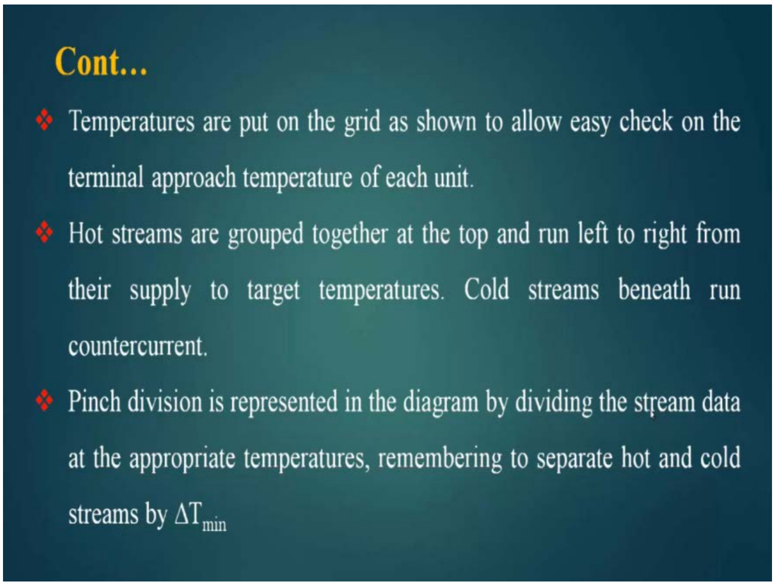
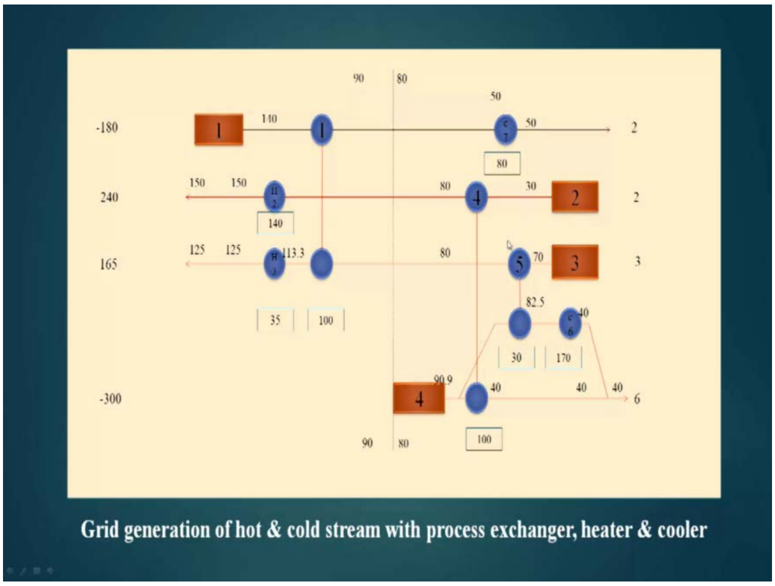


The temperature is put on the grid as shown. The hot streams are grouped together at the top cold streams are beneath and pinch division is represented by a line.

(Refer Slide Time: 40: 18)



So, let us see here it will be clearer. This is the hot stream which is drawn from left to right. This is the CP values and these are the temperature values and this is a cold stream which is drawn from right to left; this is another cold stream which is drawn from right to left and this is hot stream which is drawn from here to here. Now this shows that stream number-1 is exchanging heat with the cold stream number-3 and this is the exchanger number-1, this is a heater, this is another heat exchanger, this is a cooler, this is another heat exchanger and this is a cooler. Now, you see that the stream number 4, which is hot stream has been divided into two parts and then heat exchange is taking place.

Thank you.