Process Integration

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Module - 3
Building blocks of PINCH Technology
Lecture - 2
Hot composite Curves

Welcome to the lecture series on Process Integration. Today, we will see a very important topic that is hot composite curve. Now why a composite curve is necessary? If you look into the topics name this is process integration, and in this topic we have taken heat integration. In a industry, there are many hot streams and many cold streams; hot streams give heat and cold streams receive heat. Now, how to account for the heat, which can be transferred from the hot streams to the cold streams. Now if we add up all the heats available with the hot streams, and add up all the heat required for the cold streams and then try to make a balance will it be correct answer is no. Why, because we have considered a important parameter in the heat transfer and that is the temperature of the hot stream. We have only considered the quantity of heat, which is available with the hot streams, and the quantity of heat, which is required by the cold streams in this process.

So, when we define a stream and that stream is to be used for heat transfer we have to consider two parameters. The first parameter is temperature, because the thermodynamics tells that the temperature, the heat will flow from a higher temperature to a lower temperature naturally. So, temperature is as important as the enthalpy of the stream. Now keeping this in mind; we will try to integrate all the heats available with the hot streams, and will we try to integrate all the cold - that is all the heat required by the cold stream. In such a manner that they can be used these information can be used for the integration purpose. Now for that when we are doing integration of hot streams then we will create a hot composite curve. Today's lecture is devoted to creation of hot composite curve.

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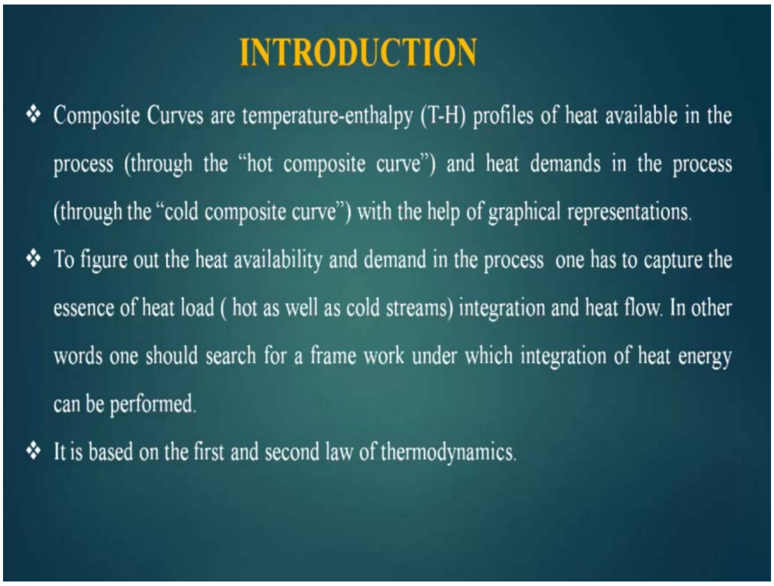

Composite curves are temperature enthalpy profile of heat available in the process through and the demands in the process through the cold composite curves with the help of graphical representation. So, that means, that we will have two composite curves - one composite curves dedicated to hot streams called hot composite curve, and the other dedicated to cold composite curve which consist of cold streams. To figure out the heat availability and demand in the process one have to capture the essence of heat load hot as well as cold stream integration and heat flow. In other words we should search for a frame work under which integration of heat energy can be performed. Now, it should be based on the principles of thermodynamics. So, how to do integration, what should be the two axis integration under which we will integrate the hot stream as well as cold stream?

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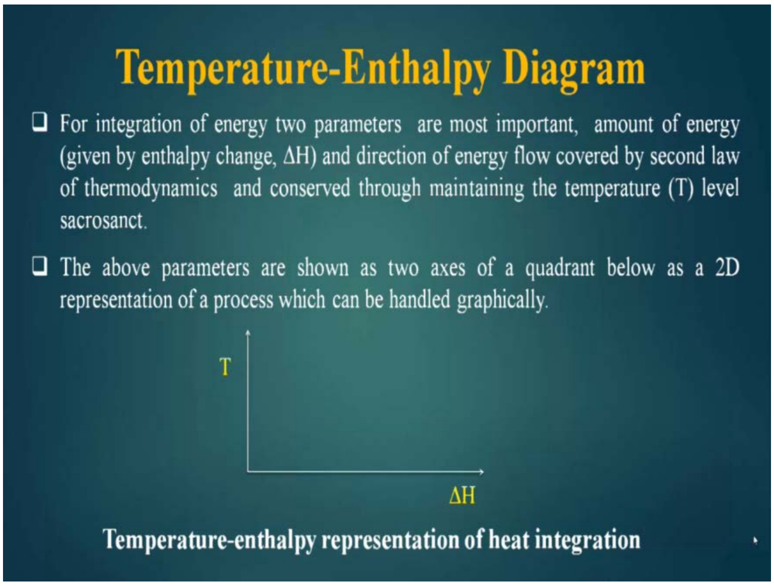

For integration of energy two parameters are most important, amount of energy that is given by enthalpy change - delta h, and the direction of energy flow covered by second law of thermo dynamic and conserved through maintaining the temperature level and this maintaining up temperature level is a sacrosanct - that means we have to maintain it correctly and it is not a deviation variable. The above parameters which we have talked that is enthalpy and temperatures are shown as two axis of a quadrant below as a 2 D representation of a process which can handle graphically. That means, we will integrate the all the hot streams and all the cold streams within a graph whose axis are y-axis is temperature and x-axis is delta H. And this graph or this plot is called temperature-enthalpy representation of heat integration.

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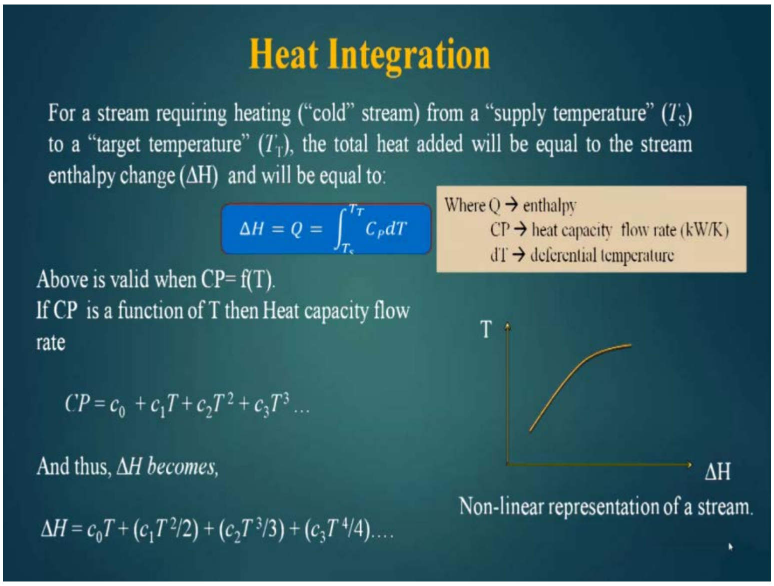

Now, for a stream a requiring heating that is cold stream from a supply temperature (T S) to a target temperature (T T) the total heat added will be equal to the streams enthalpy delta H and this can be given as delta h is equal to q equal to integration T S to T T CP dT where q is the enthalpy or which h is the enthalpy and C P is the heat capacity flow rate which is nothing but m into C P mass flow rate into C P and delta t is the temperature differential when you integrate this and if the C P is kept within the integration; that means, the C P is changing with temperature which means C P is a function of temperature and if this c p is a function of temperature this can be written as C P is equal to c 0 plus c 1 T plus c 2 T square plus c 2 T cube.

So, through a through a equation or a polynomial we can express the value of c p as a function of t thus automatically delta h also become a function of t if C P is a function of t generally in the t h diagram we get the relationship as a non-linear relationship as shown in this t h diagram now let us start analyzing whether we can put this a hot stream in a t h diagram and if we can put or you we can represent the hot stream in the t h diagram then how it should be done.

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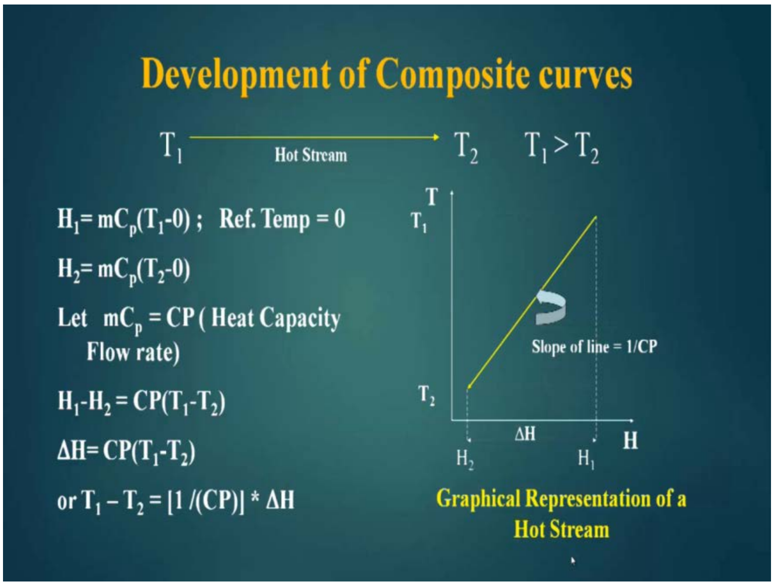

Now, the figure shows a hot stream which supply temperature is t one and its target temperature is t two were t one is greater than t two now if I want to calculate the enthalpy of the stream at t one considering reference temperature as zero then it will be m c p t one minus zero were m is the mass flow rate c p is a specific rate similarly the enthalpy at t two will be given as m c p t minus t zero in this case also we have taken reference temperature as zero now let us call m c p is equal to capital c p which is heat capacity flow rate then h one minus h two will be c p t one minus t two and we can write down delta h equal to c p t one minus t two or you can write down t one minus t two is equal to one by c p into delta h this equation is the equation of a straight line that means.

I can represent a hot stream in the t h diagram as a straight line here we have assumed that this c p value is constant and it is not a function of temperature if it will become a function of temperature then this will not be a straight line this will be a non-linear representation and it will not be a linear representation. So, if this is t one and this is t two and this is h one and this is h two then line will be the start from the intersection of t two and h two and will end at the intersection of t one and h one and the slope will be one by c p. So, here we have understood how to represent a hot stream in a t h diagram while doing so. So, we are keeping both the information which are required for the heat transfer that is t temperature and delta h this both quantity are preserved in this diagram.

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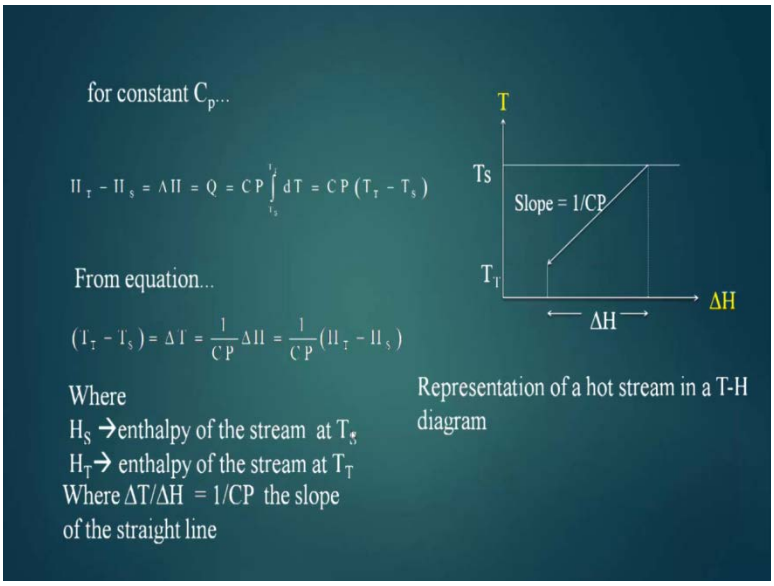

Now if c p is constant we can write down this equation t t minus t s is equal to delta t is equal to one by c p delta h this one by c p t t minus t s. So, we have seen now that how to represent a hot stream in the t h diagram now let us see what are the other properties of this t h diagram which we can harness which we can use for the integration propose when we say integration; that means, more than one hot streams are to be integrated because in the industry we can have thousands of hot stream and thousands of cold streams.

So, when we say integration; that means, we are adding more than one hot streams we have already shown you that how to plot a hot stream in the t h diagram. Now we will learn how to integrate more than one hot streams and to convert this integration into a composite curve to do this we have to explore some property of this t h diagram.

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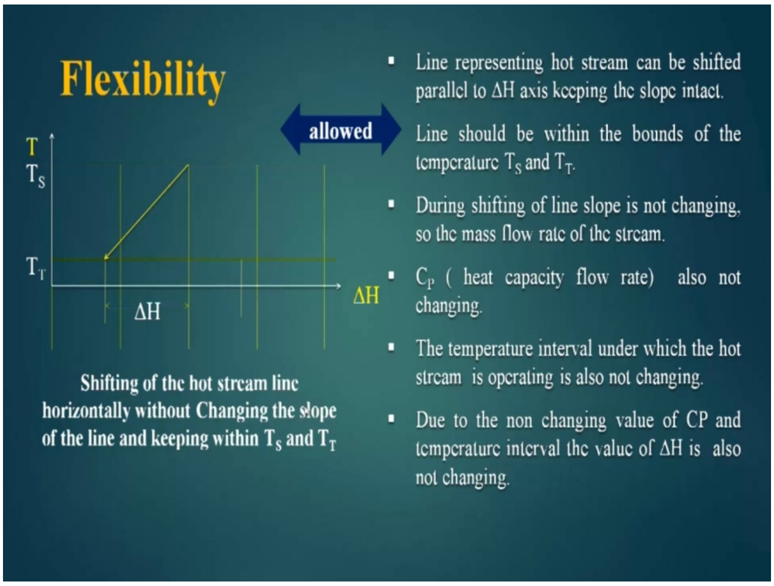

In this diagram we have seen that we have a hot stream which starts from here and comes to here which is from t s to t t and its value is delta h now if I shift this then the question is am I committing some mistake or shifting this hot stream parallel to delta h x is correct or it can be consider as correct.

So, now lets us argue it out now when I do this the line representing the hot stream can be shifted parallel to delta h axis keeping the slope intact. So, when I shifting I am keeping this slop intact this is the first thing the second thing is that the line should be within the bounds of temperature t s and t t. So, within this bounds this line always remains the third thing that doing shifting the line slope is not changing and if the line slope is not changing then the mass flow rate of the stream is also not changing and we have also assume that the c p capacity flow rate is constant for this case.

So, this is also not changing; that means, the total aim c p which is capital c p is not changing when I am doing this shifting the temperature interval under which the hot stream is operating is also not changing because the stream is always remaining within the limits of t s and t t and its input temperature which is t s which is called supply temperature it touches the supply temperature and the target temperature due to non changing value of c p and the temperature interval value and the delta h all this three things are not changing; that means, if I keep this line or I shift this line parallel to delta h the t s and t t temperature are not changing the delta h is not changing mass flow rate is not changing c p value is not changing; that means, I can shift or shifting of this representation of the hot stream parallel to delta h should be allowed. So, shifting of hot stream line horizontally without changing the slope of the line and keeping with t s and t t each permission now here I.

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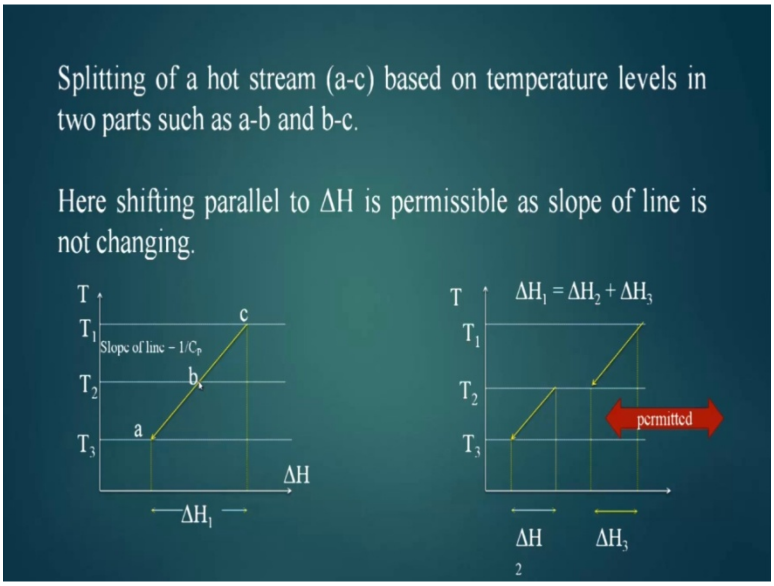

So, here hot stream which start at c point ends at a point; that means, it start at t one and goes to t three and if I draw a artificial temperature level t two which intersect this line at point p now question is that whether I can break a hot stream which starts at t one and targets to t three into two parts and can shift one part from its place. So, if I do this, so acutely what I am doing is shown by the animation. If I am doing this it is also permitted because shifting of a line or a part of this line parallel to the delta h axis is permitted now when I am breaking this into two lines separate lines the enthalpy of the overall curves also remain constant; that means, it is delta h one which is the overall enthalpy of this hot stream is equal to delta h two plus delta h three which are the enthalpy of the part of this lines; that means, this is also permissible the third property which we see that whether I can shift the hot stream vertically upward that is parallel to the t axis.

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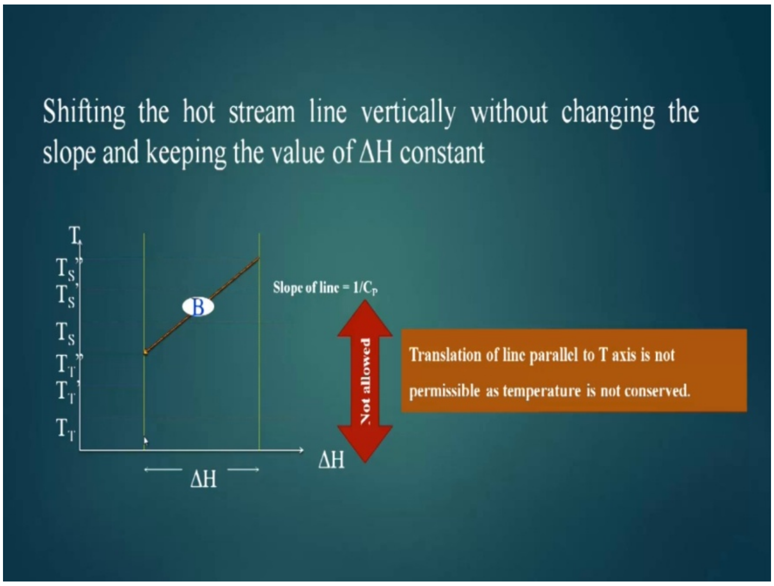

So, this figure shows shifting of the hot stream line vertically without changing the slope and keeping the value delta h constant whether this is permissible or not now when I am shifting this line which is a hot stream line its supply temperature is t s and the target temperature is T T when I am shifting this and bringing to a position a what I can find that its supplied temperature as well as target temperature is changing to a new value t s dash and T T dash. If I further shift it to a position b then it is changing again to T s double dash and T T double dash.

Now while doing so, what is happening, I am tempering the supply and target temperature, which is not permissible, and hence it is not allowed. Why it is not permissible, suppose a cold stream is at T T temperature and the hot stream in first instance the hot stream was here now when the hot stream rises up to here now this stream is in a position to give heat to this cold stream which is which was here now this is not possible because the temperature of the hot stream was lower than the cold stream and by shifting it artificially I have made its temperature above the cold stream and by doing so.

I am artificially allowing it to supply heat to the cold stream which is not the actual case and hence when we shift the hot temperature curve vertically upward we are changing the supply and target temperatures and we are evaluating the fundamental thermo dynamic law that is second law and hence it is not acceptable. So, what we saw that horizontal shifting is allowed were as vertical shifting is not allowed. So, translation of line parallel to t axis is not permissible as temperature is not conjure

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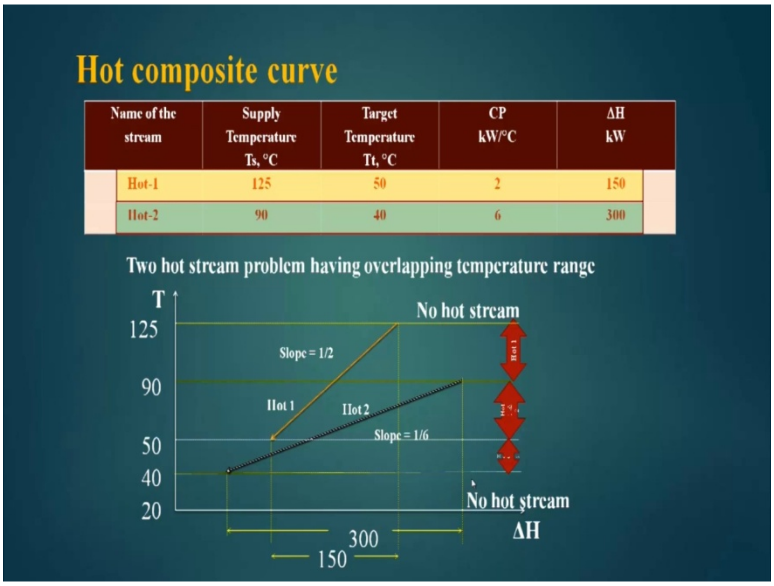

Now let us take tow hot stream one hot stream is from hundred twenty five to fifty degree centigrade its supply temperature is hundred twenty five degree and its target temperature is fifty degree its c p value is two and its transferring hundred kilo watt that is another hot stream which is hot stream two it starts from ninety degree centigrade and its target temperature is forty degree centigrade its c p value is six and it is transferring six hundred kilo watt of heat.

Now, if I want to represent this two hot stream in the t h diagram they will be represent like this the first hot stream it will be represented like this it is hundred twenty five degree centigrade to fifty degree centigrade and the slope of this line is one by two the second line the hot stream which is called hot stream number two which is supply temperature is ninety degree and the target temperature is forty degree this can be represented by another line which is called hot two line slope is one by six and the delta h is three hundred.

Now, let us try to analyze these hot stream number one is working from 125 degree to 50 degree centigrade. These are the temperature levels of hot stream number one whereas, the temperature level of cold stream is from ninety oh sorry hot stream number two is from ninety to forty now in this temperature level forty to fifty only hot stream number two is working and from fifty to ninety both stream are working hot one and hot two both are there in this temperature range fifty to ninety and then above ninety to hundred twenty five only hot stream is present; that means, if there is cold stream which is between ninety to hundred twenty five somewhere only hot stream.

Number one will be able to give heat to it were as if the cold stream is somewhere here or below ninety to fifty degree centigrade both hot stream one and cold hot stream two can give heat to that cold stream and if the cold stream is within the temperature level forty to fifty or below it then only hot stream two will be able to give heat to that cold stream what it tells that in temperature level between the temperature level 50 to 90. There is a possibility of integrating the heat of hot one and hot two.

So, here in this region 20 to 40 there is no hot stream and this region is only serviced by hot stream number two this region is serviced by hot stream number one and two and this temperature level is only serviced by hot stream number one and there is no hot stream present beyond 125 degree centigrade. Now the question is how to add this up and if we find out a way to add them up in the region were more than one hot stream is present we will create a hot composite curve.

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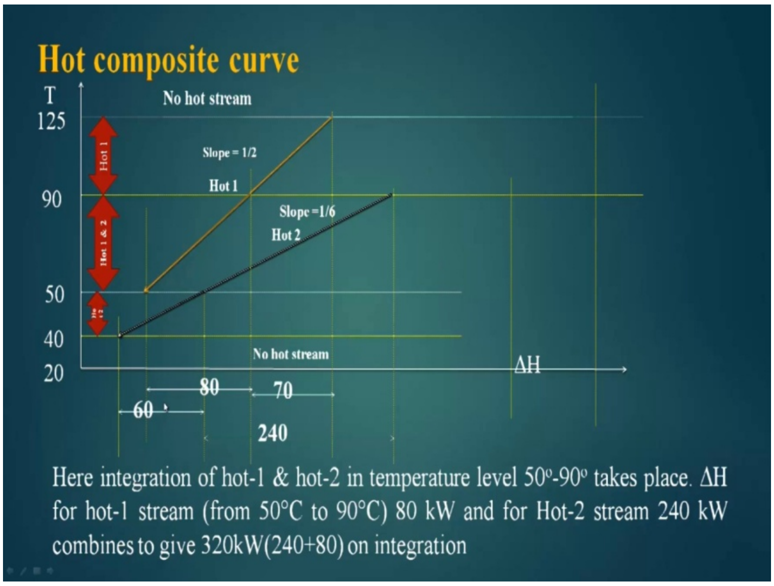

And let us see how to do it. So, here we see that we are finding out some we have broken the hot streams into different part here from this temperature to this temperature hot stream is transacting 60 kilo watt of heat and from this temperature to this temperature it is 240 kilo watts.

Now, why we have broken like this because from temperature level 50 to 90, 240 kilo watt of heat is available from hot stream number two and for the same interval that is fifty to ninety hot stream is in a position to hot stream number one is in a position to give you eighty kilo watt of heat and from this 90 to 125 only hot stream number one is present and it is able to give you seventy kilo watt of heat.

So, according to power analyses as from fifty to ninety both streams are present they can be hided up and in this temperature interval that is 50 to 90 the total heat available from both hot one and hot two is equal to 80 plus 240. Whereas in this temperature level 40 to 50 only hot two is available and in this temperature interval 60 kilo watt of heat available to transfer similarly from temperature 90 to 125 only hot one is present and here the heat availability is 70 kilo watt now we have to find out the way to do this and represent this in terms of a hot composite curve. Now what we can do we can break this into two part and this part shifted here and we can add this two lines and when we add this two line the heat available with this two line will be joined and its slope will change.

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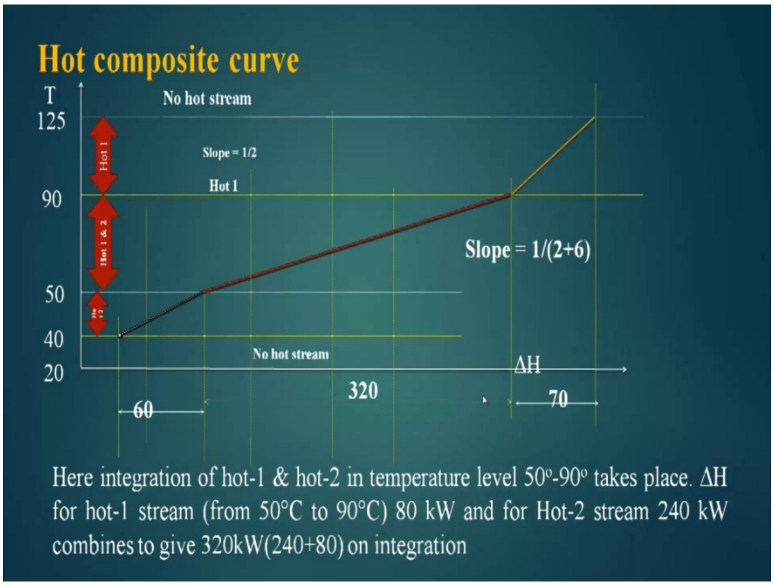

So, we draw a third line which represents the both line or combination of both line and its heat availability is three hundred twenty which is nothing, but the summation of 240 plus 80 and then we can translate this to this position and this is 70. So, from here to here hot two is only available which gives 60 kilo watt of heat from here to here hot one as well as hot two are available it gives 300 kilo watt of heat and from here to here which is hot two hot one it gives 70 kilo watt and if you add this 60, 320 and 70 it gives the total heat available with the hot one as well as hot two now this shows a simple method of integrating two hot streams and this whole curve from here to here is called a hot composite curve and in this composite curve there are two hot stream present.

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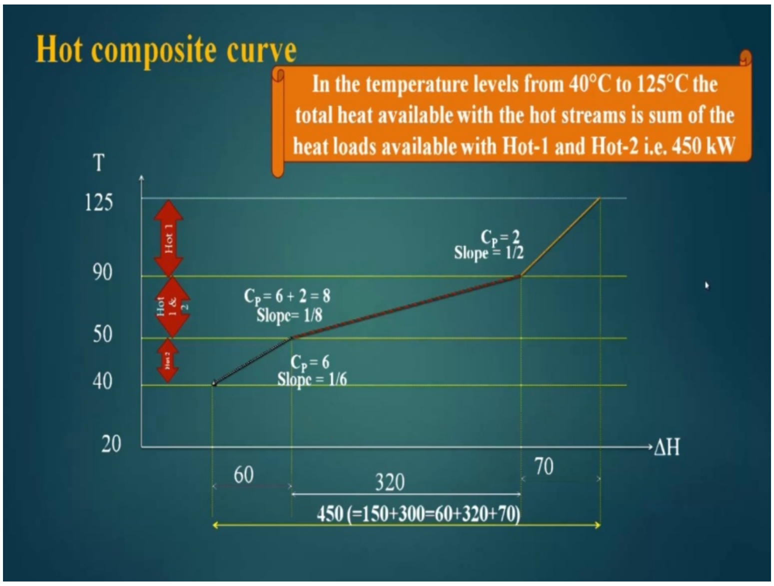

And the slope of this line from here to here will be one by the summation of c p value this is capital CP this is small cp this is also a capital c p this is also a capital C P. So, the slope will be one by eight which is one by summation of the C P of the two hot streams and the total heat available is 450 which is equal to the heat available with the first hot stream 150 and heat available in the second hot stream which is 300 and this is also equal for 60 plus 320 plus 70.

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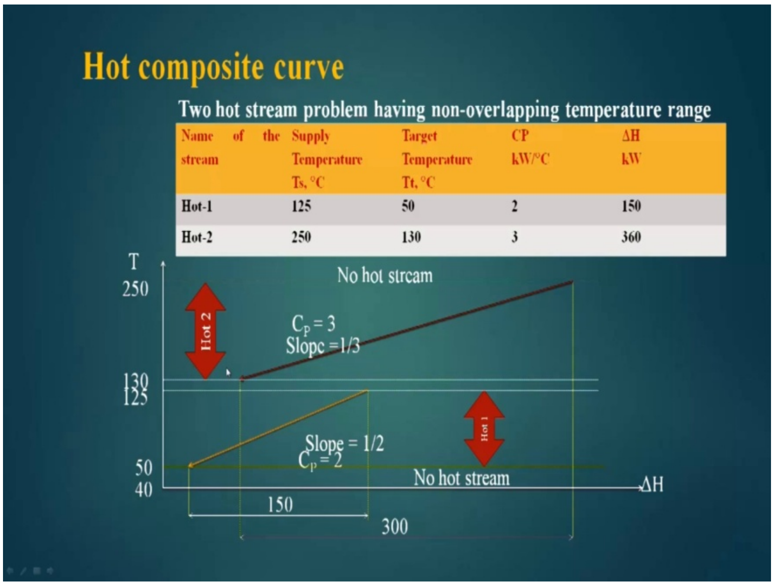

Now if there are hot stream which are non overlapping then what will happen. So, we take another example were there are two hot stream problem having non overlapping temperature range. So, the hot stream number one has a temperature from 125 to 50 degree and c p is two and the second stream is 250 to 230 and c p is three and the heat available with hot stream number one is 50 kilo watt and number two is 360 kilo watt now if I represent this in this t h diagram the my hot stream is from 125 to 50 and hot stream number two is from here to here.

So, they are not overlapping if they are not overlapping then I do not have temperature level a range of the temperature level were both are present the stream hot stream number one is moving from hundred twenty five degree centigrade to fifty degree centigrade at c p value capital c p value is two. So, slope is one by two number two capital c p value is three this is capital c p value is three. So, slope is one by three and there is gap between this two it start from here it starts from here to here and it starts from here to here. So, there is no overlapping part hot stream is probably here to here and hot stream two is from here to here if we come across such a situation then how to integrate this let us see.

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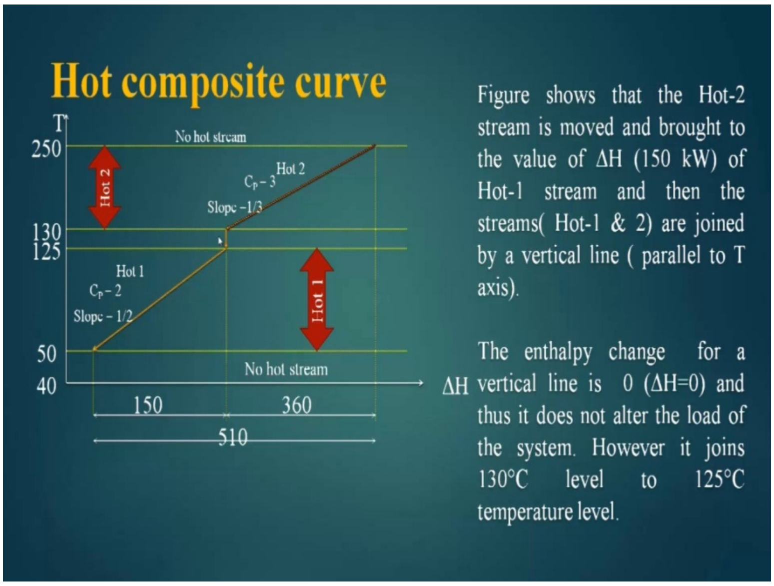

Now, this is the same situation here I have marked all enthalpy temperature level here also c p is capital c p here also c p is capital c p now we can translate this to this level and then we can join this with vertical line when I am joining this with the vertical line this line has a value of delta s equal to zero this figure shows that the hot two stream is moved and brought to the value of delta h hundred fifty of the hot stream one; that means, I will shift this up to this level to this and then stream hot and hot one and hot two are joined by a vertical line parallel to t axis.

So, this is the vertical line parallel to t axis the enthalpy change for a vertical line is zero its delta h is zero and thus it does not alter the load of the system; however, it joins hundred thirty degree centigrade level to hundred twenty five degree centigrade level. So, by joining them with the vertical line whose delta h is zero I am not altering the heat contain of this two lines and hence I am not effecting the heat balance and that is why joining this two by a vertical line is perfect and it should be acceptable now let us take a three hot stream problem having non overlapping temperature range the first two are taken from earlier problem we have added a third stream hot stream which is from two hundred sixty to three hundred degree centigrade.

Now, this is the representation of all these three hot stream on this graph hot stream number one is from hundred twenty five degree centigrade to fifty degree centigrade hot stream number two is from two hundred fifty degree centigrade to hundred thirty degree centigrade and hot stream number three is; obviously, starts from here may be two hundred sixty degree centigrade now for integration what we have to do we shift this to this level and then we will shift this to this level parallel to this delta h that is x axis and then we join them by vertical lines. So, we are joining here by lines.

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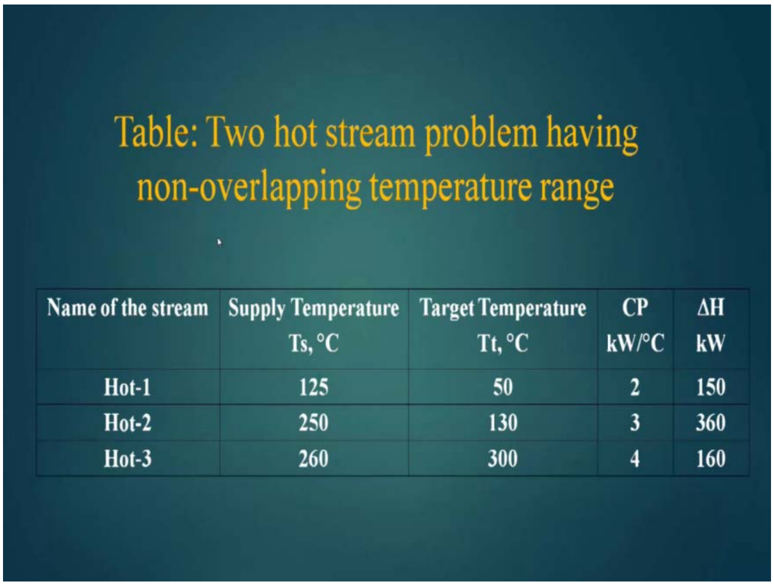

Name of the stream	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH kW
Hot-1	125	50	2	150
Hot-2	250	130	3	360
Hot-3	260	300	4	160

So, for this three hot stream problem this then this.

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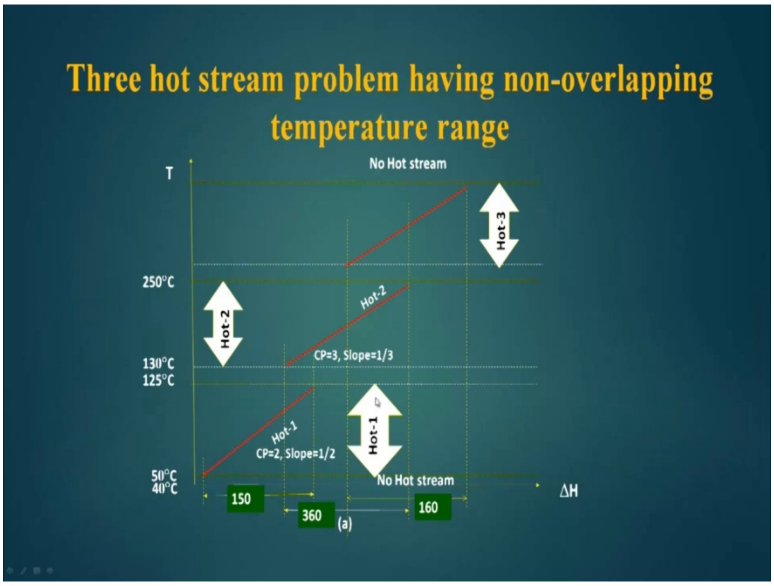

This then this then this whole line is shows the hot composite curve for this three hot streams which are non overlapping in temperature range.

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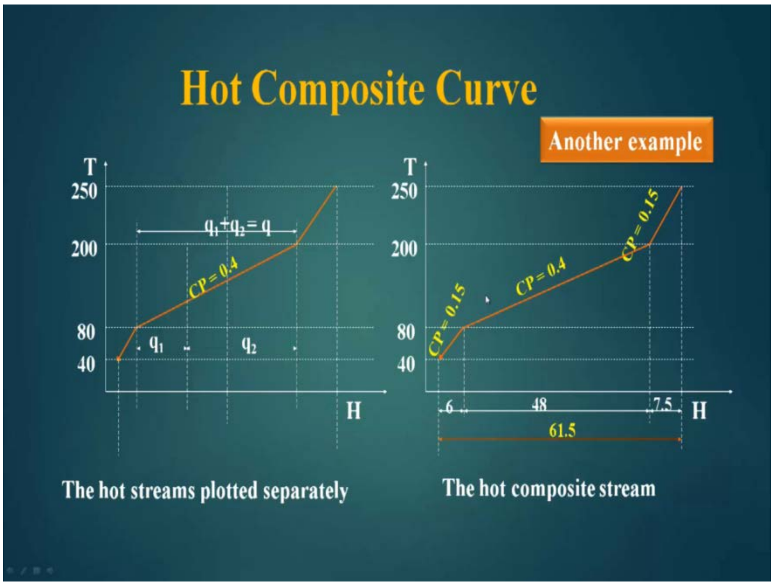

Now, let us take the another example we have one hot stream which start from hundred starts from two hundred fifty degree centigrade to forty degree centigrade whose c p value is zero point one five.

Now the second hot stream is from two hundred to eighty whose c p value is point two five the heat available from eighty degree to two hundred degree with hot stream say one is q one and in this same temperature range; that means, two hundred to eighty where hot stream number two is working the heat availability is q two.

So, when we integrate this two stream in this temperature level because they are available in this temperature level what I except that integrated temperature line will have a h value delta h value which will be equal to q one plus q two. So, I can bring this two here and then I can join both I can draw a line which enthalpy value is equal to q one minus plus q two as I have told you earlier and its c p value becomes the addition of both the c p values and slope is equal to one divided by the addition of the c p values of both the line and then I can shift this to here to form the hot composite curve I can shift this to form the hot composite curve.

So, this hot composite curve which is composed of two hot streams is from here to here. So, this complete line is called hot composite curve which consist of two hot streams in the similar manner I can add n number of streams hot streams and create a hot composite curve for n number of stream this is a graphical method which have been shown to you;

however, you must have felt that this graphical method is somewhat tedious and it is difficult to carry out if the number of streams are more, but this graphical methods gives you a insight how the streams are added.

So, it gives you the fundamental platform or the foundation platform in which the hot streams are integrated and a hot composite curve is created we will see in other lectures that a computer based algorithm has also been developed to integrate this hot streams because most of algorithm are changing to computer algorithm to do it quickly and accurately. So, this shows you the final composite curve now we will see that what is the mathematical foundation for load integration of streams we have used this concepts earlier, but I am showing here what is the mathematical foundation of it for that here.

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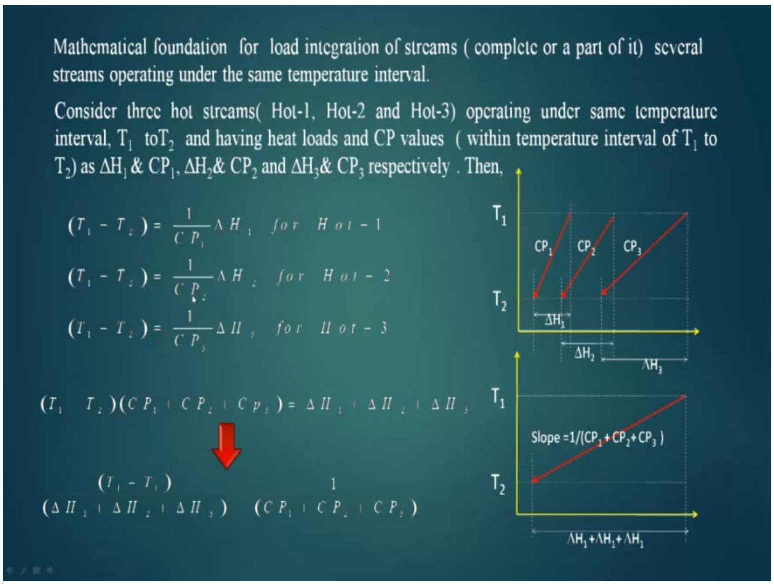

We have a figure in which we have used three hot streams hot one hot two and hot three and they are working in the same temperature intervals of t one and t two this three hot streams are represented in the t h diagram here all the three hot streams are working one under the interval t one and t two the first hot stream is from here to here t one to t two and its c p value is c p one and it is transacting a enthalpy delta h.

One the second hot stream is from t one to t two again and its c p value is c p two and it is transacting delta h two enthalpy the third hot stream is again from the same interval temperature t one to t two and its value is c p three and it is transacting heat delta h three now we have seen earlier that if a number of stream are in the same temperature interval its gives as a scopes to integrate the heat of all this hot stream and to merge it and to form a composite hot curve now we see this mathematically what will be the enthalpy of that merge curve and what should be the slope of that merged curve now for this example I can write down that t one minus t two is equal to one by c p one into delta h one and this is for hot stream number one similarly for hot stream number two I can write down t one minus t two is equal to one by c p two into delta h two which is for hot stream number two.

Similarly, for hot stream number three I can write down t one minus t two is equal to one by c p three delta h three and this is for hot stream number three what I can do I can multiply c p one to t one minus t two then it becomes t one minus t two into c p one is equal to delta h one similarly I can multiply c p two with this delta t one minus t two then it becomes t one minus t two into c p two is delta h two similarly I can multiply here c one minus c two into c p three is equal to delta h three.

Now, I can add delta h one plus delta h two plus delta h three and I can take common factor that is t one minus t two if I take the common factor it becomes t one minus t two into c p one plus c p two plus c p three is equal to delta h one plus delta h two plus delta h three I can write down this t one minus t two divided by the summation of the enthalpy values delta h one plus delta h two plus delta h three is equal to one by the summation of the c p values c p one plus c p two plus c p three.

Now, if I take this delta h one into delta h delta h one plus delta h two plus delta h three this side it becomes t one minus t two this would be t two t one minus t two is equal to one by c p one plus one by c p two plus one by c p three into delta h one plus delta h two plus delta h three is this represent the equation of the line and the resulted line can be represented within that temperature interval t one and t two and its slope will be equal to one by c p one plus c p two plus c p three and the enthalpy contain of this line will be equal to delta h one plus delta h two plus delta h three.

So, we have seen that if there are three hot streams in a certain temperature interval how they can be integrated and the what will be the slope of the composite line and what will be the amount of enthalpy that composite line will contain in this way we can integrate a number of hot streams in a certain temperature and we can form a composite curve. These are the references.

Thank you.