Process Integration
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Module - 3
Building Blocks of PINCH Technology
Lecture - 3
Cold Composite Curves

Welcome to the lecture series on Process Integration. In the lecture number 2, we have demonstrated how the integration of hot stream can be done through a graphical method. Using this method, all the hot streams of a industry can be integrated. I would like to convey this that when we are going for a integration in a industry, and that integration is an energy integration or a heat integration. Then we would like to find out that how much heat is available in the industry, what is the requirement of the industry as heat for the cold streams and how much hot streams can give heat to the cold streams.

In many situations, you will find that the hot streams have heat with them, but it cannot be given to the cold stream. For example, if a hot stream is available at hundred degree centigrade to 70 degree centigrade it cannot give a heat to a cold stream which is at 200 degree centigrade and rises to 250 degree centigrade; that means, all the hot streams which are available in the industry cannot give their heat to all the cold streams. Why this has happened because due to the temperature constants, if a hot streams temperature is higher than the cold streams temperature then only as per the thermodynamics natural flow of heat will take place.

Further, we have seen in the lecture number two that while we are doing integration of hot streams. There are two important parameters - the first parameter is that we have to keep the temperature intervals intact while doing the integration, and the second important parameter of the integration is the amount of heat which are available with the hot streams. Now after integrating the all hot streams and developing the method of integration of hot streams, we will see how the cold streams can be integrated and by integrating all the cold streams we will create a cold composite curve.

As we have created a hot composite curve by integrating the all the hot streams and then this hot composite curve and the cold composite curve will be used to estimate how much heat internally can flow to the cold composite curve, and what is the heat requirement of the industry which be supplied from outside. And what should be the cold utility requirement we should be supplied from the outside. Now, this gives a better picture of heat integration of a industry, and talks about the possibility of transferring the heat from outside actual as well as from the inside. Now let us see that what are the advantages of the composite curves. We already know how to create a composite curve or how to create a hot composite curve and that is why it is now time to discuss that what are the advantage of this and then we will proceed how to create a cold composite curve.

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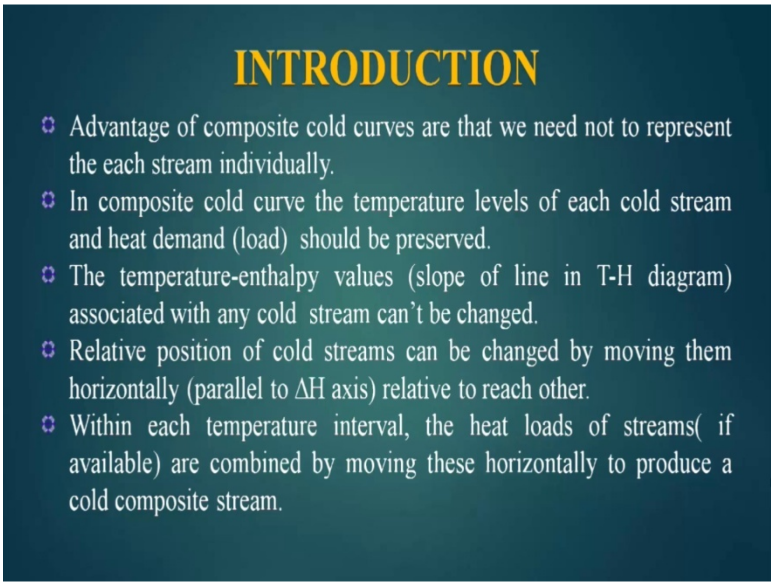

Advantages of composite cold curves are that we need not represent the each streams individually if we start tackling each streams separately then; obviously, the complexity of tackling it will increase. So, this is always advisable that all the cold streams should be integrated to form a cold composite curve the second thing is that cold composite curve the temperature levels of each cold stream and heat demand should be preserved; that means, the supply temperature of the cold stream and the target temperature of the cold stream and how much heat is required to heat the cold stream from its supply temperature to the target temperature should be given or should find a part in the composite cold curve.

The third thing is that the temperature enthalpy values. The slope of line in T H diagram associated with any cold stream cannot be changed, if I am changing the slope. What I am changing is the C p value, and when I am changing this C p value either I am changing the mass flow rate or I am changing the C p that is specific heat or I am changing both as the stream have fixed c p values and mass flow rate values, this cannot be changed. We will see situation when C p values also change due to the temperature when a cold stream is undergoing temperature change this may be possible in some of the cases that the C p value will change because the specific heat is a function of temperature in such a case when the change in C p value is high.

The T-H diagram of the cold stream converts into a non-linear diagram. That means, it is not a straight line and in those cases in the lecture number one, we have seen that we can approximate the non-linear lines into multiple linear lines showing that. In those temperature intervals there is not a considerable change in the value of C p relative position of cold streams can be changed by moving them horizontally parallel to delta x axis related to each other this we have seen. And we have also proved in the hot stream integration that the relative positions of the cold streams with respect to each other can be changed. And this does not add to any problem in the analysis of or in the creations of the cold composite curve within each temperature interval, the heat load of the stream are combined by moving these horizontally to produce a cold composite curve. We will see here also that the integration takes place in a temperature interval where more number of cold streams are available then one.

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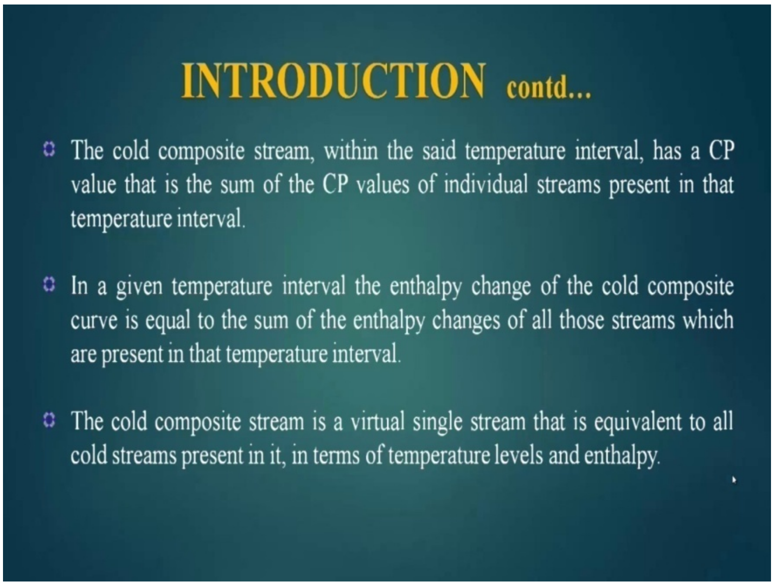

So, the integration take place within a temperature interval not between two temperature intervals that we will see further the cold composite stream within the said temperature interval has a C P value that is the sum of the C P values of individual streams present in that temperature interval that we have seen for hot streams we will see this for cold streams and we will see that what is the mathematical background behind this and we have given it in the lecture number two.

In a given temperature interval the enthalpy changes of the cold composite curves is equal to sum of the enthalpy changes of all those streams which are present in that temperature interval this we have seen for the while we were doing integration of the hot streams to convert into a hot composite curve the cold composite streams is a virtual single in this we should remember when we are converting all the cold streams into a colds composite stream it is a virtual stream and it is not a single stream, it is composed of many streams and in different temperature intervals different number of streams will be available in this though after integration it appear as if it is a single stream it is not correct and that is why we say that cold composite curve or cold composite stream is a virtual single stream it is not a actual single stream and it is composed of many streams.

Now, we see why we have selected at temperature enthalpy diagram this temperature enthalpy diagram is the bases of heat integration within this temperature enthalpy diagram we will integrate many cold streams into one virtual cold streams now let us try to examine what is the inherent quality or what is the inherent parameter of a cold stream which are required for integration, if we analyze this as discussed in earlier we will find there are two parameters one is temperature of the cold stream that is supply temperature and the target temperature and the enthalpy of the cold stream which is required to heat the cold stream from the supply temperature to that target temperature.

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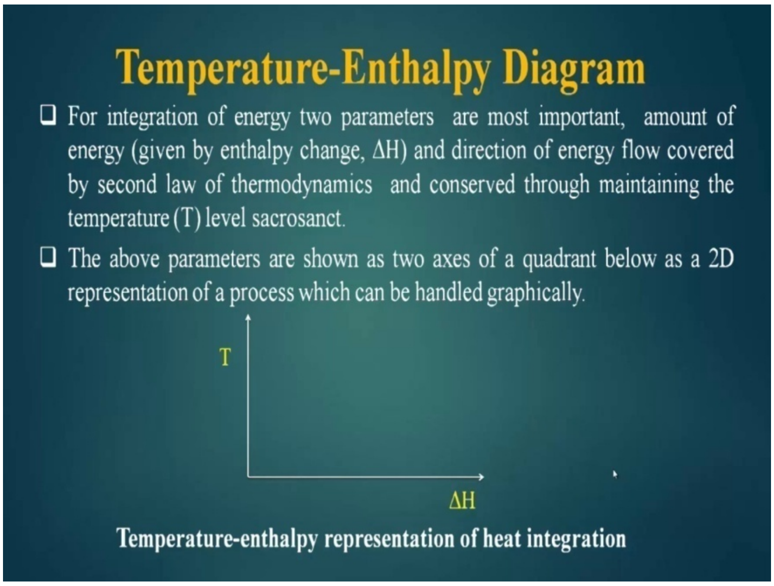

Temperatures are cycleution, we cannot change the level of temperature, but delta H is a value which is a differential in nature; that means, it is not absolutely in the sense we will see this that while sliding a cold stream parallel to delta H axis maintaining the delta h value will not create a problem now if a cold stream I had already told you if a cold stream is at a 100 degree centigrade and the hot stream is at 80 degree centigrade the hot stream cannot give heat to the cold stream now if that cold stream which is at 100 degree centigrade it is brought down by shifting the line or artificially shifting the temperature interval to 60 degree centigrade.

Now, the hot stream will be able to pass on heat to that cold stream and hence in actual as it is not possible to pass on heat from a temperature to higher temperature it is not advisable that the temperature levels of the any stream should be changed. So, we see that there are two parameters which are represented as the axis of a plot and this two parameters are temperature level and delta h. So, within this boundary of t and delta h we will try to integrate all the cold stream available now let us try to see that what is the relationship between the delta H and the t values. Now, when we select a stream may be a hot stream or a cold stream at this lecture is for cold stream we will talk about cold streams.

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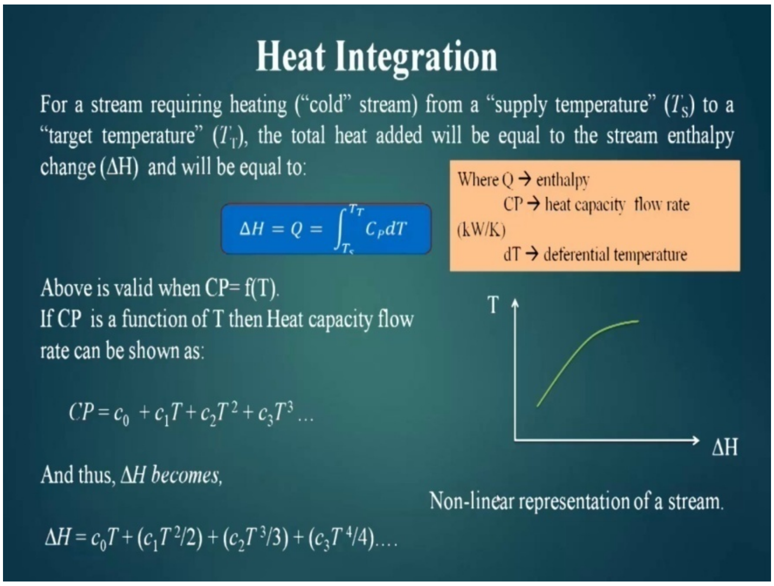

The cold stream has a supply temperature which is represented by t s and has a target temperature which is represented by t t suffix t the supply temperature is the temperature at which the cold stream is made available and the target temperature is that temperature up to which it has to be heated up by either by hot stream or by a hot utility now if we change the temperature of a cold stream from t s it supply temperature to t t targets temperature what will be the enthalpy change in this cold stream can be retain as delta h is equal q q is equal to integration t s to t t c p d t if the c p is inside the integration it means c p is a function of t and if it is not a function of t then we can bring out it from the integration in general case c p is a function of t and can be represented by a polynomial c p is equal to c zero plus c one t plus c two square plus c three t cube so on so forth.

As c p is a function of t then delta h is also becomes a function of t if c p is changing drastically or substantially with temperature then the representation of the cold stream in the t h diagram will not be a linear line it will be a non-linear line as shown in the graph this is a non-linear line it is a linear it a not linear line as c p is changing with temperature; however, this can be approximated to two straight lines one from this point to this point. And another from this point to this point and the artificial temperature interval can be created and we can break this cold stream into two parts based on the linearity of the stream.

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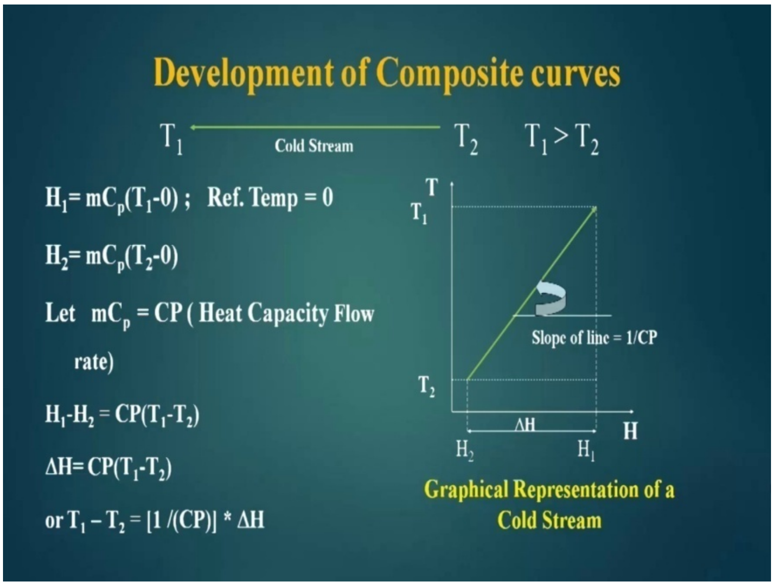

Now, let us developed a mathematical relationship to graphically present this cold stream in the t h diagram where t is the y axis and h or delta h is the x axis if I am able to represent this cold streams as a equation then I can plot it this in the t h diagram. So, let take a cold stream cold supply temperature is t two and target temperature is t one such as t one is greater than two. And if I take the reference temperature has zero then the enthalpy of the cold stream h one which is at temperature t 1 is equal to m c p t one minus zero similarly the enthalpy at t two which is h two will be m c p t two minus zero here I am taking reference temperature to be zero if I consider that m c p is equal to capital c p which would be called heat capacity flow rate, then I can write down h one minus h two is equal to capital c p t one minus t two and t one minus t two is equal to one by c p into delta h now this was the equation of the line and I can plot this cold stream into t h diagram.

So, the cold stream will start from t one and will end at t two and we will have a slopes such that its projection on h axis is delta h and slope of this line will be one by c p. So, we have learned now how to place a cold stream on a t h diagram once we know this we can place all the cold stream which are available in the industry into t h diagram once the cold stream are plotted like this the second stage of the operation is to integrate those cold streams and to create a virtual composite cold stream now let us see that how a cold stream can be integrated with the other cold stream.

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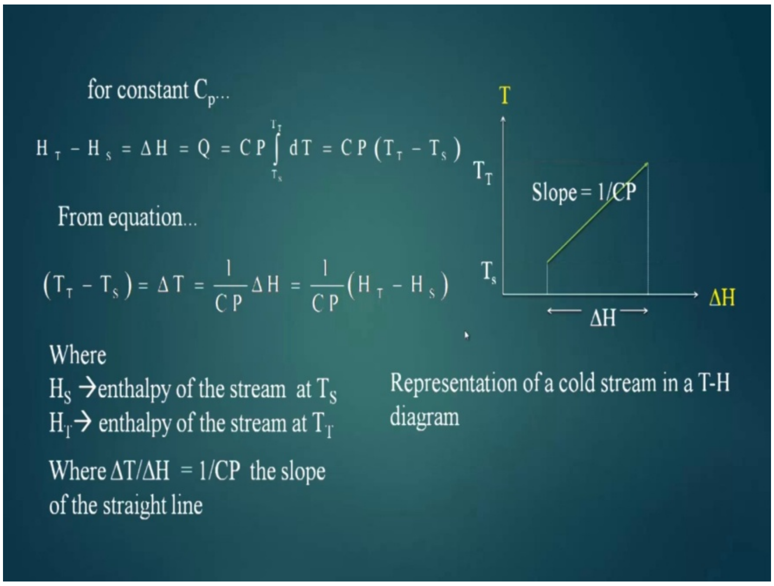

Now, for constant c p we see that this will c p will come out of the integration and we will see this relationship c p equal to t t minus t s and this forms the equation after knowing how to place a cold stream in a t h diagram the second job is to integrate it before we start integration let us see the property of this t h diagram that what it allows and what it does not allow.

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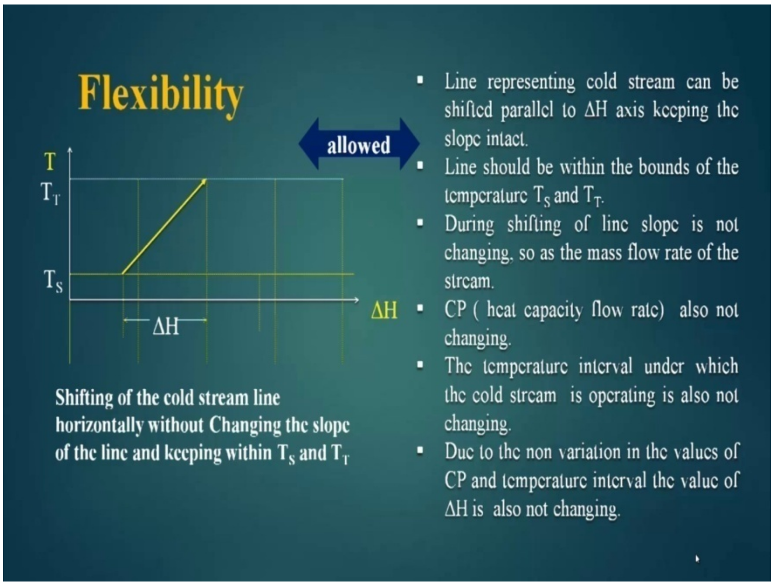

Now, in this figure let us see there is a cold stream which start from supply temperature t s to t t was slope is constant and it requires delta h amount of enthalpy to heat it from t s to t t. Now, if I translate this cold stream parallel to the delta h axis then let us see whether this would be allowed or this should be allowed if it is changing the vertices it is sending the important parameters associated with this cold stream when we are sliding this horizontally then it should not be allowed if it is not changing those vertex not changing those important parameters or pertinent parameters then we should allow this translation now one by one let us check it line representing the cold stream can be shifted parallel to delta h axis keeping in this slope intact now when I am sliding this a I am not changing this slope of the line the line always remains in the temperature interval t s to t t.

So, while pushing it in the horizontal directions parallel to delta h axis I should not change the slope if I am not changing the slope what I am not changing is the multiplication of mass flow rate and specific heat as the streams which I am handling have a constant mass flow rate and its constant specific heat, because I am representing them at straight lines and if I am keeping the slope intact I am not changing this two qualities or the this two quantities would which are pertinent nature the second thing is that the line should be within the bounds of the temperature t s and t t because earlier I had told you that this t t and t s is synchronize cannot change this, because if you change this I mean violate this second law of thermodynamics the third is that during shifting of the line slope is not changing I had already proved. So, the mass flow rate and c p values will not change the temperature interval under which the cold stream is operating is also not changing.

Now, if all this pertinent parameter which are mass flow rate c p value temperature interval and the delta h value is not changing with this sliding of this line which represents a cold streams if it is. So, then it is allowed because the pertinent parameters are not changing. So, due to the non variation of the values of c p and temperature interval the value of delta t is also not changing and hence shifting of the cold stream line horizontally without changing the slope of the line and keeping t s and t t intact is allowed.

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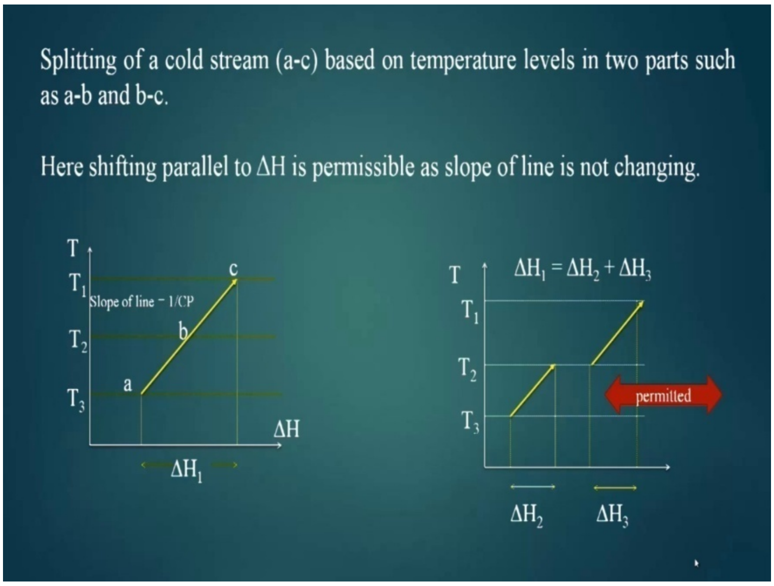

Let us see a second property that whether the cold stream can be splitted or not now this shows a cold stream which is operating in the temperature interval t one and t three where t three is the supply temperature and t one is the target temperature and it slope is one by c p.

Now, the question is can I break it at t two which is a artificial temperature interval and then I can translate horizontally the broken part b and c. So, let a see this if I do. So, this is permitted because I am not changing the c p value there and plus delta h two plus delta h three is equal to delta h one while delta h one is the enthalpy change when the cold streams moves from a two c and delta h two enthalpy change when it moves from temperature t three to t two which is a to b and deltas h tree is the enthalpy change when it is moving from b to c.

So, the addition of enthalpy of the a two b and b to c is h one. So, combinely this two streams have the enthalpy of the original course stream there are mass flow rate and c p is not changing their overall temperature levels are not changing only they are splitting into two streams. So, splitting a stream in to two streams and horizontally shifting one part of the stream parallel to the x axis what is h axis is permissible.

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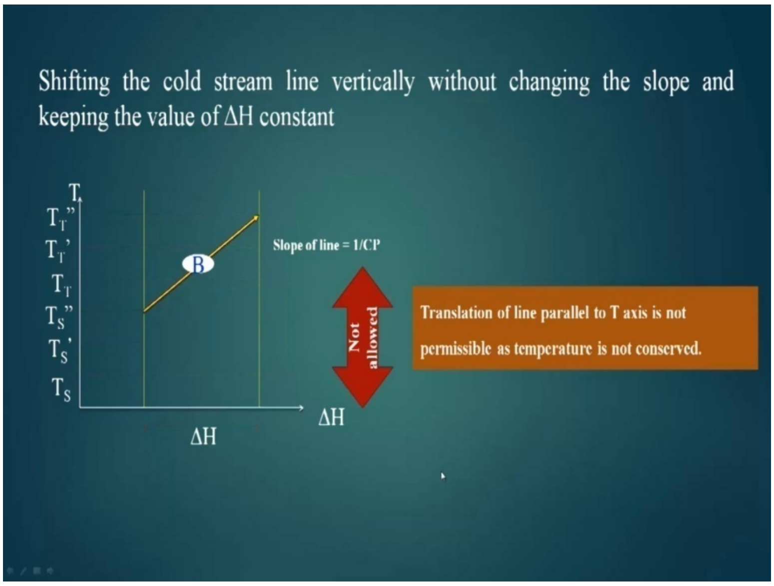

Let us see in the t h diagram if a cold stream is shifted vertically then what happens for this purpose we are showing a cold stream which supply temperature is t s and target temperature is t t. Now it slopes is one by c p and while translating it vertically upward I am not changing c p value; that means, I am not changing.

The mass flow rate and this specific heat multiplication factor; however, when I shifting it to horizontally up to position a its supply temperature changes to t s des and the target temperature changes to two t t des this is changing the temperature level of the cold stream further if I shift it to a position b then the supply temperature becomes t s double des and the target temperature becomes t t double des, now when the shifting take place what is happening it supply temperature and target temperatures are changing as I have told that temperature are pertinent parameters they are very important parameters. And we cannot shift them or we cannot change them in the pinch analysis because it will violate the thermodynamics principles and we will give false information about the transfer of heat as it plays with temperature levels when we are shifting it vertically upward parallel to the t axis this such type of shifting is not permissible and hence it is written that it is not allowed.

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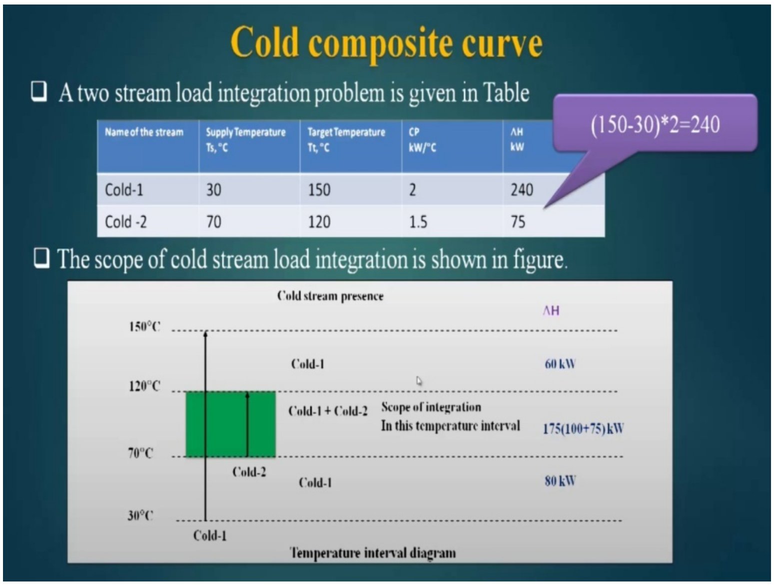

Let us now try to learn how to integrate cold streams if they are more than one in a t h diagram for that we have taking a stream table where there are two cold stream the first cold stream supply temperature is thirty and the target temperature is hundred fifty and its c p value is two and it is transiting a heat of two hundred forty kilo watts the second stream which is the another cold stream has a supply temperature of seventy target temperature hundred twenty and has a c p value of one point five and its transiting seventy five kilo watt no how how we are calculating the delta h values delta h values are equal to the delta t into the m c p value in this case it calculation has been given hundred fifty minus thirty into two is two hundred forty.

Now, if this cold stream are being plotted in a diagram then we see very clearly that from thirty to seventy degree centigrade only cold stream one is available from seventy to hundred twenty degrees centigrade cold one and cold two are available and from hundred twenty to hundred fifty degree centigrade only cold one is available. So, in the temperature level seventy to hundred twenty there are two cold stream available cold streams as well as cold stream one as well as cold stream two. So, it offers me a opportunity to combine this two cold streams ain this temperature intervals seventy two to hundred twenty.

So obviously, if I see the heat required by cold stream one from thirty to seventy degree centigrade is eighty kilo watt and this can be calculated as seventy minus thirty into the c p value to which comes out to be eighty kilo watt; however, in the temperature interval from seventy to hundred twenty two cold streams are available the cold stream one and cold stream two the change in enthalpy one will be hundred twenty minus seventy into two and the changing enthalpy of cold stream two is seventy five. So, for the cold stream number one it becomes hundred for cold stream number two it becomes 75. So, when we add them up it becomes 175.

So, heat requirement in this interval seventy to hundred twenty is hundred seventy five which is the requirement of both the streams in this interval if we see the interval from hundred twenty two to 150 only cold stream one is available and the heat requirement is sixty kilo watt. So, this we have calculated by our calculation and this should be reflected in the composite curve when we are integrating it through the composite curve.

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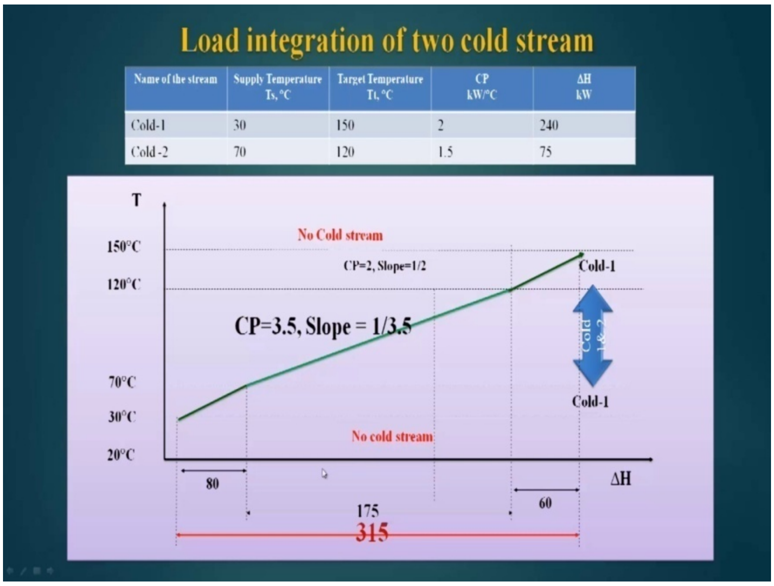

Now, if we place this cold stream one and cold stream two we are taking thus and if we want to integrate this within the temperature interval of 70 to 120 we see from temperature interval 70 to 120 both streams are present. So, integration will be done in this temperature intervals. So, this shows how we have integrated both streams in the temperature interval seventy to hundred twenty and then the broken part of the cold stream one is shifted to join this integrated curve which is from here to here and it added here while maintaining the slopes now this total curve is the cold composite curve and if you see here from thirty to seventy only cold one is present here from seventy to hundred twenty cold one and cold two are present here; that means, two streams are present here and from here to here that is hundred twenty to hundred fifty only one stream that is cold one is present this composite curve is a fictitious curve.

Because it appears as if it is one stream, but this is not one stream because from this to this thirty to seventy one stream is available from seventy to hundred twenty two stream are available and from hundred twenty to hundred fifty again one stream is available and the overall enthalpy from here to here is three hundred fifteen which is the summation of this two enthalpy two hundred forty and seventy five and this interval where integration has taking place seventy to hundred twenty the overall enthalpy is hundred seventy five which was calculated by us earlier the slope of this line will be one by summation of the c p values the summation of two c p value this is 2 plus 1.5 is 3.5. So, this slope of this integrated line will be 1 by 3.5. So, this is the required composite curve.

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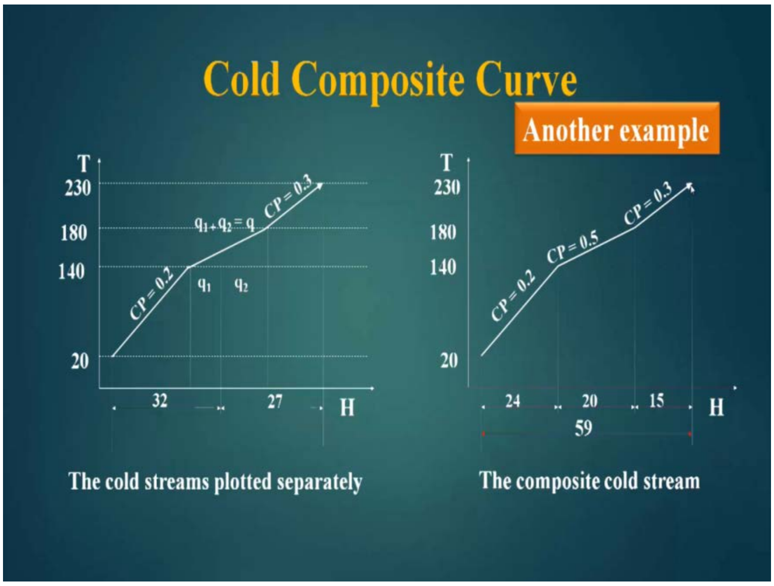

Let us take a another example we have two cold streams and the both cold streams are present from hundred forty to hundred eighty. So, it keeps its scope for integration. So, I have broken this line and shifted this to this and then it forms a line which is a integrated cold composite and then this line remains. So, we have a cold composite curve in this case where c p value of this is 0.2 c p value of this is 0.5 because it contains two cold two cold streams and again from here to here it contains one cold streams c p value is 0.3.

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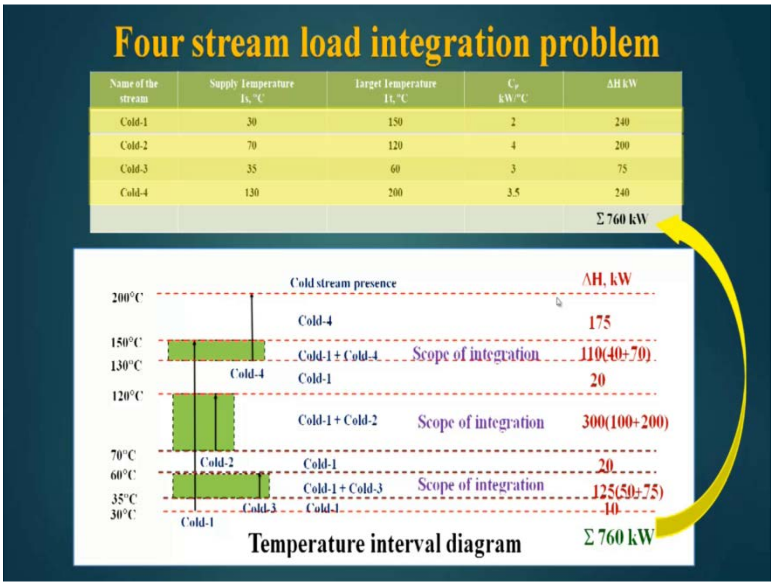

Let us take a four stream problem where we have four cold streams cold one cold two cold three and cold four and we can have a temperature interval plot. So, cold one is from here to here cold two cold one is from thirty degree to hundred fifty degree cold two is from seventy to hundred twenty cold three is from thirty five to sixty and cold four is from hundred thirty to two hundred if you see this we find that in this temperature interval one thirty to hundred fifty cold four is present as well as cold one is present.

So, there is scope of integration in this temperature level in this temperature level seventy to hundred twenty cold one is present as well as cold two is present and hence there is scope of integration here and in this region 35 to 60 cold one is present and cold three is present. So, there is a scope of integration here. Now if you do the integration mathematically we find that the delta h values which are available from hundred fifty to two hundred it is hundred seventy five from hundred thirty two hundred fifty there are two cold streams if I add the delta values of these two streams it comes out to be forty plus seventy is equal to hundred ten from this hundred twenty two hundred thirty only cold one is available its delta h is twenty from seventy to hundred twenty two streams are available cold two and cold one its integrated value is hundred plus two hundred three hundred and from this sixty to seventy only cold two is available its cold one is available.

Sorry, cold one is available its enthalpy is 20 and from 35 to 60 cold one as well as cold three is available its combine delta h is 125 and from 30 to 35 cold one is available its value is ten enthalpy value is ten and when I add them up it becomes 760 and if I add all this four it becomes 760. So, its shows that a integrated cold stream will have the same enthalpy of the all the cold streams which are available for the integrations.

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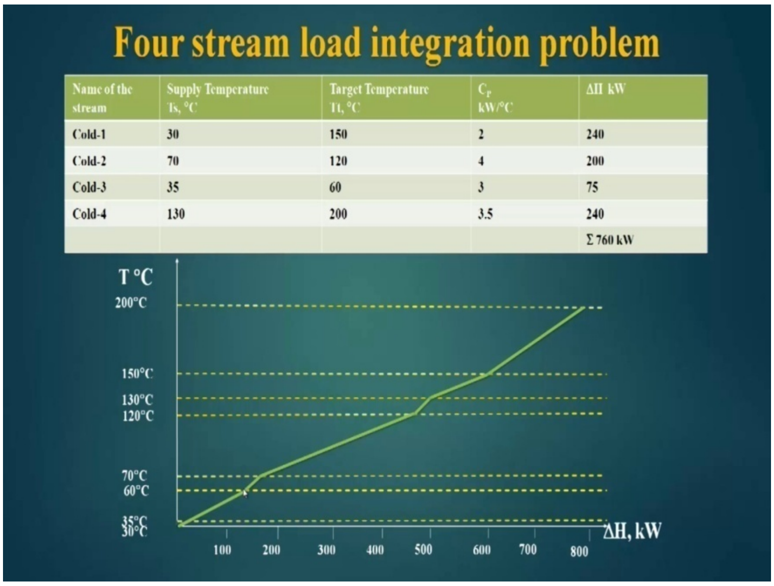

This shows you the integrated cod streams was stream data is available here now you will see that there are changes of the slopes this changes takes place in the temperature intervals; that means, you will find changes either in 30 70 35 130 or 150 120 60 and 200; that means, this change in slope will occur were the supply or the target temperature of a cold streams falls.

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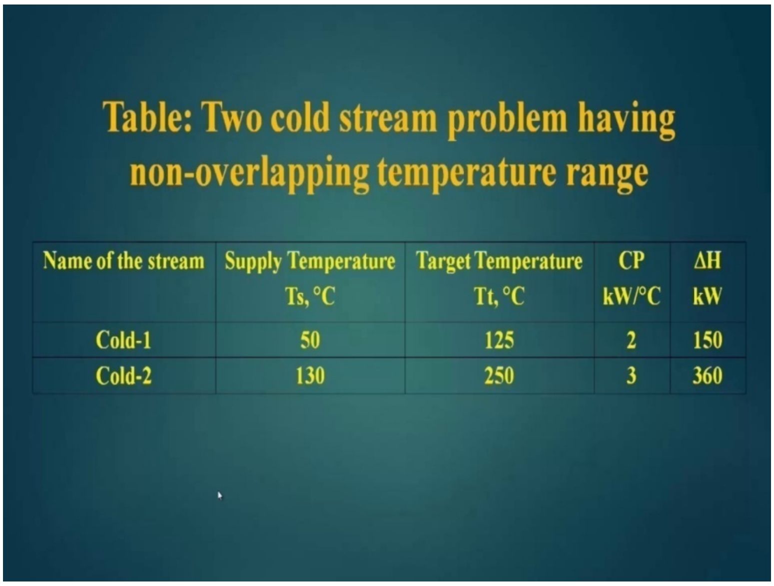

Name of the stream	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH kW
Cold-1	50	125	2	150
Cold-2	130	250	3	360

Now, let us take another problem where there is non- overlapping of temperature ranges; that means, the temperature range of cold one is not over lapping with the temperature range or temperature interval of cold two, then how to integrate them because we have seen that integration is only possible when there is a overlapping temperature range.

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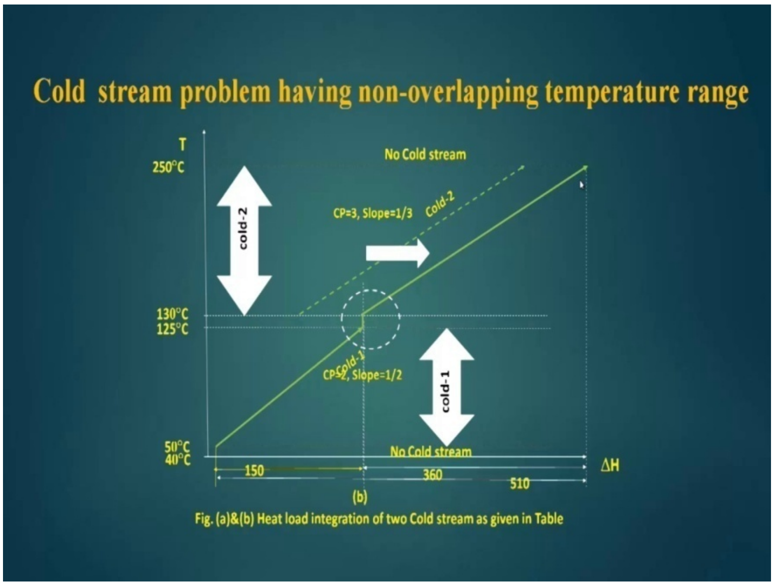

Now, this shows the temperature levels of two cold streams the first cold stream temperature level is from 50 to 125, and for the second cold stream it is 130 to 250 and there is gap here 125 to 130 were is where no cold stream is present now if I want to join this two cold streams and form a composite curve how do I go we will see that if a such situation has arrived in which the temperature levels under which one cold stream is operating and the temperature rebel under which the second cold stream is operating are not over lapping with each other now how to tackle and convert this into a composite curve.

So, in that case what we will do we will shift the cold to this point and then join the target temperature and the supply temperature of cold to with the target temperature of cold one with a vertical straight line when I am joining it with the vertical straight line the delta h value of this straight line which represent a fictitious cold stream is zero and hence I am not changing the enthalpy balance of the whole systems if I am not doing that then it is permissible because this streams joins hundred twenty five to hundred thirty is a fictitious cold streams having delta h value equal to zero. So, the overall composite curve is now from here to here then here and then from here to there. So, this represents the overall composite curve of two cold streams which are non over lapping in nature in that temperature range.

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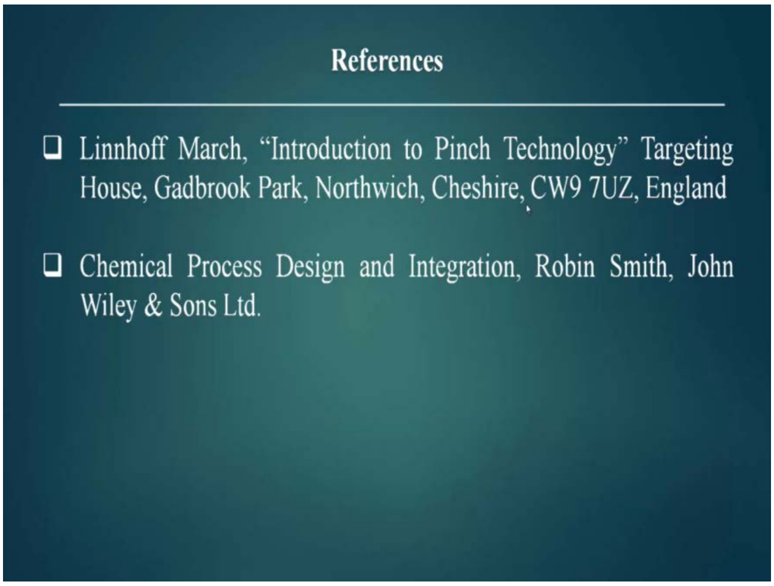

This is references, and then thank you.