Mathematical Modelling and Simulation of Chemical Engineering Process
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Lecture 41
Pinch point Temperature

Hello everyone, today we are going to talk about the Pinch point temperature. Essentially, we will try to explore our process in the context of more than one hot and more than one cold stream. So, if you have 2 hot and 2 cold streams, how to prepare the composite temperature curves in the T-H temperature enthalpy diagram and from there try to identify what is the pinch temperature. So, pinch temperature is the point or is the location I would say in this temperature enthalpy diagram, where the difference between the hot or the composite hot and the cold composite cold curve is minimum, that is what we call as the pinch point.

Now, in the previous class, we have seen already for single stream and I mean seeing a single hot and single cold stream, I mean it is obvious that the pinch would be at the lowest possible temperature or the lowest possible temperature of the cold stream. But this is not necessarily true when you have multiple streams and each of these streams at different value of their CP Capital CP.

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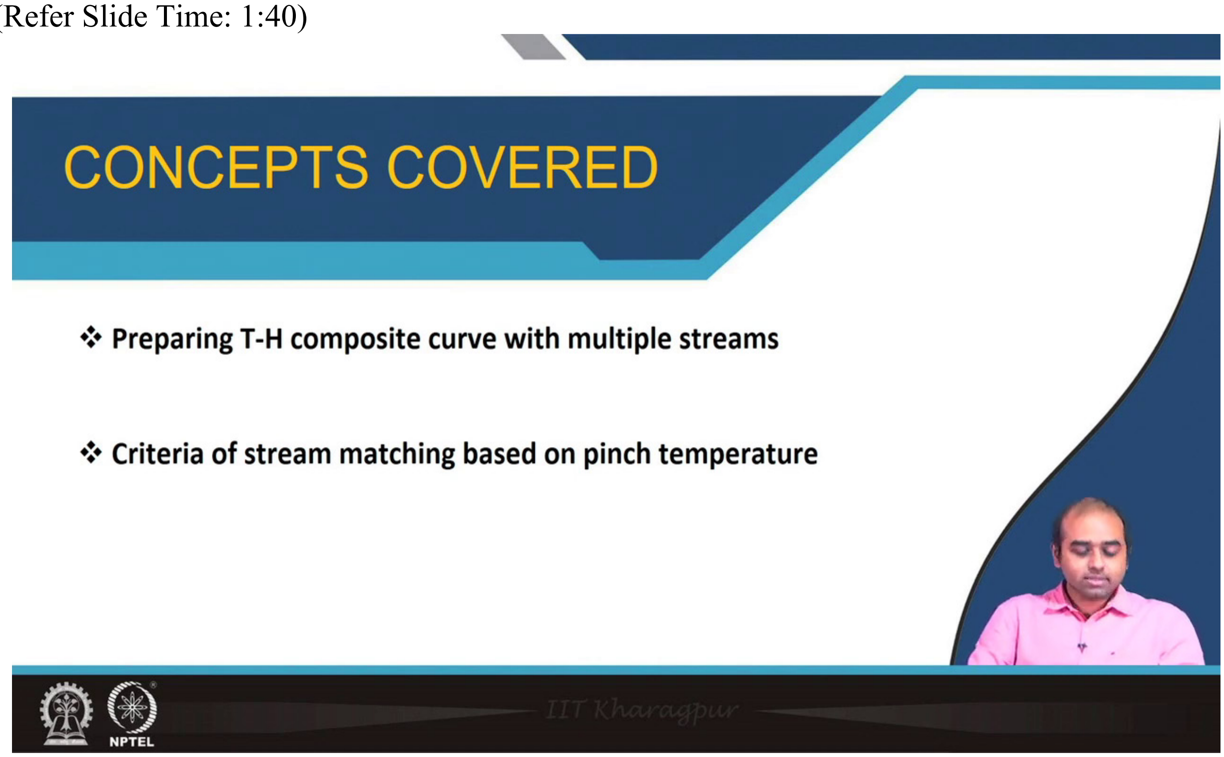

So, let us look into this case when you have multiple streams into the systems, how can we prepare the composite this temperature enthalpy curves considering multiple stream or more than one stream. And then try to find out that what essentially is the pinch temperature or the pinch point and think about that how what are the different criteria or the conditions which has to be satisfied across the pinch for potential stream matching in the heat exchanger network configuration. And then in the next class, we will talk about the heat exchanger network synthesis.

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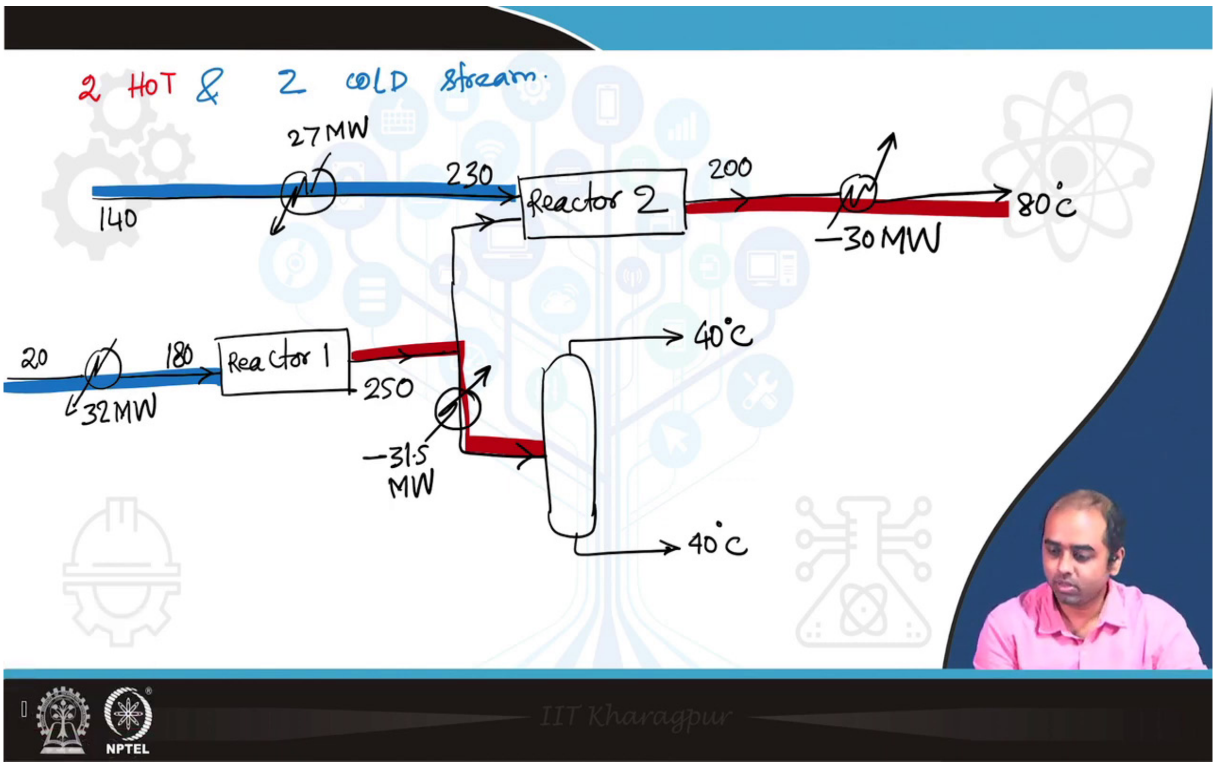

So, let us today look into a situation when we have these 2 hot streams and 2 cold streams. So, 2 hot and 2 cold streams. So, let us look into a process flow diagram of a system where you have let us say something like this you have a reactor, let us say the feed it is that is coming to the reactor it is heated. So, the feed that is available is at 20 degrees after it passes through the heater it becomes 180 degrees and it is fed to the reactor.

Now, in the outlet of this reactor is at 250 degrees and this bifurcates into two streams, one stream goes to the separator, where you have another top and bottom product of the separator, let us say both these products are at 40 degrees top and the bottom product and this one goes to another reactor. So, in this this is reactor 2. So, in this reactor there is also another stream it needs to components or two species and this reactor let us say it is also heated. So, as to raise the temperature from 140 to almost 230.

So, this reactor has 2 streams reactor 2 has 2 streams, one is coming at 250, another is coming at 230 almost close temperature and the outlet is at 200 degrees and this needs to be cooled down to 80 degrees. So, the delta H values is mentioned for these different utilities that we you can see at this moment. So, this is 32 megawatts, this is 27 megawatts, this is minus 30 megawatt. So, into the separator that is, it is also needs to be the temperature needs to be reduced. So, we add one utility here. So, as to cool down this. So, this is minus 31.5 megawatts.

So, from here you can easily identify what are the hot streams and which are the cold streams. So, cold streams are supposed to be heated up. So, here this is this is one of, let me mark it using a highlighter. So, this is one cold stream. So, cold stream as you know needs to be heated up and this is another cold stream. So, these two are the cold stream in this system and about the hot stream. So, this is one hot stream where it releases heat and this is another hot stream.

So, there are 2 hot stream I mean this is initially even though it bifurcates essentially one stream, where you try to reduce the temperature I mean I should not draw this part it is essentially the stream that is losing the temperature that is 250 to 40 degrees it is coming, that is the hot stream. So, there are 2 hot stream and there are 2 cold streams in this system, is not it? So, let us try to list down the stream configuration here. So, let us try to talk about that what are the individual CPs and other properties in this problem. So, let us try to list them down. So, where shall I write, in the next slide maybe.

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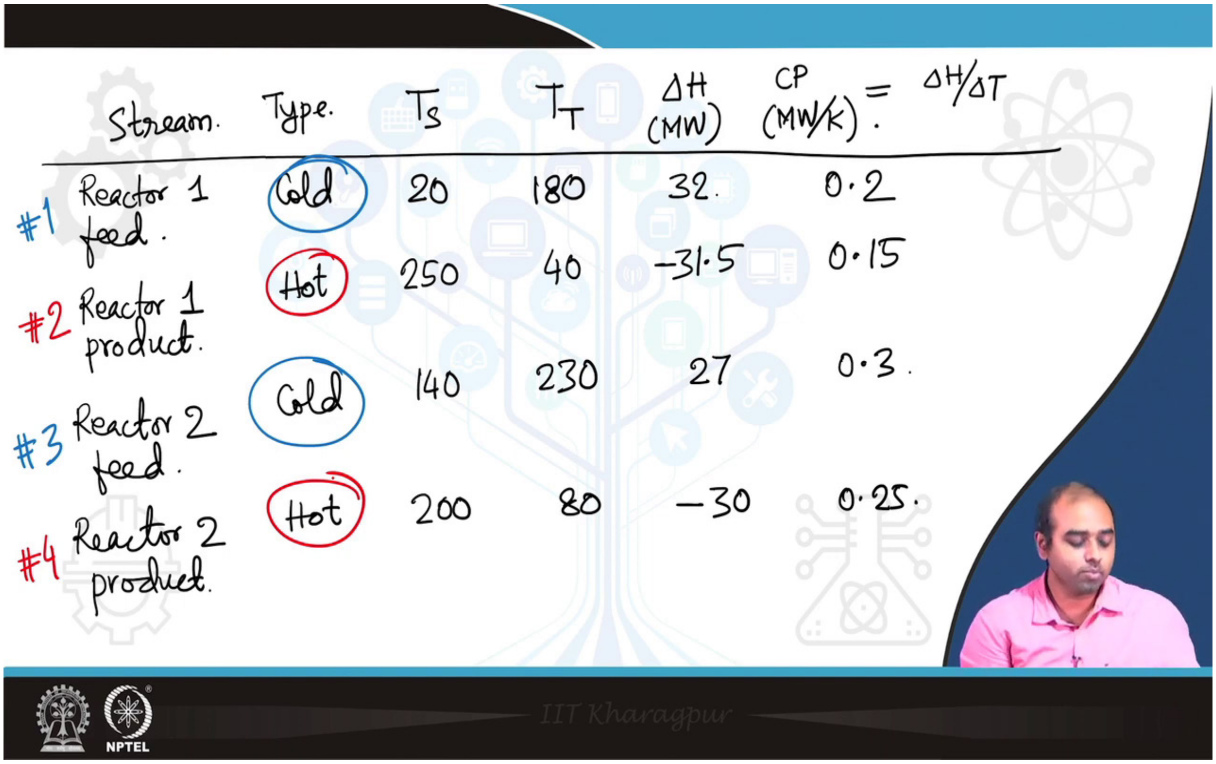

So, let us say the stream sorry. So, the first stream, write it in a big way, stream then let us write down the type, it is start temperature supply temperature target temperature or temperature it is increased to delta H value in terms of megawatt and from there we can calculate out what is the CP. So, that is megawatt per kelvin.

So, the first stream is the feed to the reactor. So, the reactor one feed is one stream and which is of course cold because that is getting heated up from 20 degrees to 180 degrees, is not it. So, that needs to be heated out and the delta H requirement for this stream is 32. So, if you work out the numbers you will get the CP value as 0.2.

The next one is the reactor 1 product. This is of course a hot stream because it is the I mean the product side is at 250 degrees and further it is cool to 40 degrees and the delta H requirement for this stream to cool up to this much value is minus 31.5. So, that gives you a CP value of 0.15, is not it? So, I hope all of you realize CP is delta H by delta T.

Then we have the reactor 2 feed, the reactor 2 feed is cold because it is at a temperature of 150 but it was 114 it was heated to 230 degrees delta H requirement was 27. So, this makes the CP as 0.3 and reactor 2 product is again a hot stream because it is I mean the outlet of reactor 2 is at

200 degrees and it is reduced to 80 degrees. So, the delta H was minus 30. So, CP value was 0.25.

So, we can realize that this is a hot stream let us mark that as stream number 2 and stream number 4 these are 2 hot streams. And this is 1 and 3 are cold stream. So, this is cold stream, this is cold stream and these two are the hot stream 2 and 4. Well the temperature in one case is from 250 to 40 in another case it was 200 to 80. Now, let us try to draw the temperature enthalpy diagrams first, we will try to work out the hot stream and then the cold stream the composite curves.

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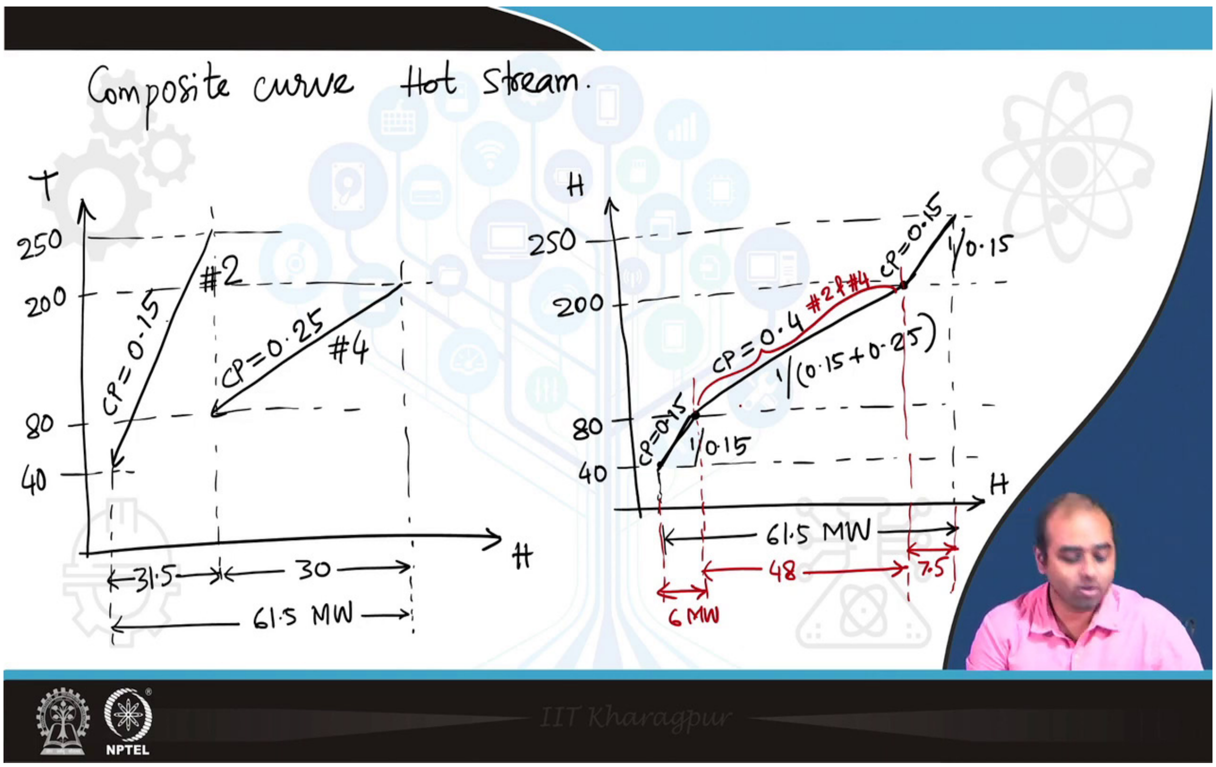

So, in the case of the hot stream, we have 2 hot streams. So, if I try to draw the T-H diagram, there is one case where we have these like reducing from hot cold, I mean changing I mean the temperature drop was from 250 to 40 degrees. So, this is curve 2 where the CP was 0.15 and there was another curve, sorry let me draw it properly which drops from 200 to 80 degrees let us say draw that separately like that.

So, this is a stream 4 where the CP value is 0.25. So, higher is the CP value the lower is the slope. So, the delta H value for stream 2 is 31.5 and for stream 4 it is 30. So, total we have 61.5

megawatts of enthalpy available from the I mean that can be released by the hot stream. So, these are two different strings. So, how do I prepare composite one. So, composite one is that in, so you have three temperature segments in this case one is from 40 to 80 and that is from 80 to 200 and that is from 200 to 250. So, from 40 to 80 it is only stream 2 from 80 to 200 it is both stream 1 and stream 2 which can supply heat.

So, these are the temperature zones where the heat or the enthalpy can be supplied by both the (temp) streams and in the region from 200 to 250 only stream 2 can supply the heat. So, using this idea the composite curve looks something like this. So, remember the x axis is always in absolute scale. So, I can always translate this curve stream 2 or stream 4 in the x axis as I wish and ultimately it is a delta H that matters. So, I can place them anywhere on the x axis and I can shift them horizontally anywhere I like.

So, this is, so this let us mark the three different zones. So, in between this zone 40 to 80. you have only this stream 2 that is supplying the heat. So, in this case the slope is 1 by 0.15 then from 80 to 200 it is supplied by both the streams. So, in that case I would draw something like this where the slope is given by 1 by 0.15 plus 0.25, this is the effective slope in this part where the energy is contributed or the enthalpy in this part from 80 to 200 in this zone is both by stream 2 and stream 4.

And then further I am having another part which is up to 250 where the enthalpy is only by stream 2. So, this part the slope is again 1 by 0.15. So, this part and this part these two are like parallel lines I do not know if this looks parallel line or not but at least these are parallel lines you can understand. So, from here, from here till the end of this part totally will be having essentially, I mean that is how the slope will also give you that value 61.5 megawatts of energy.

So, essentially the CP for this part is 0.15 but the CP for this composite part is 0.4, is not it. This part is CP is equal to 0.15 and here also CP 0.15. So, if you look closely, I mean you can also work out what is the temperature in, I mean this enthalpy provided in these temperature zones. So, in this part we are having temperature sorry enthalpy of 6 megawatts then this is another part. So, this part we are having 48 megawatts of enthalpy that is available in the temperature zone from 80 to 200.

And similarly, in this part the remaining part that is 7.5 megawatts of energy that is available in this case. So, here this composite part I will repeat this part once again the composite part whatever we are having is provided by both stream 2 and stream 4. And in this part, it is only stream 2, I mean 80 to 40 and 200, 250 it is only stream 2. So, this is how we draw the composite curve for the hot stream similar way we can draw it for the cold stream.

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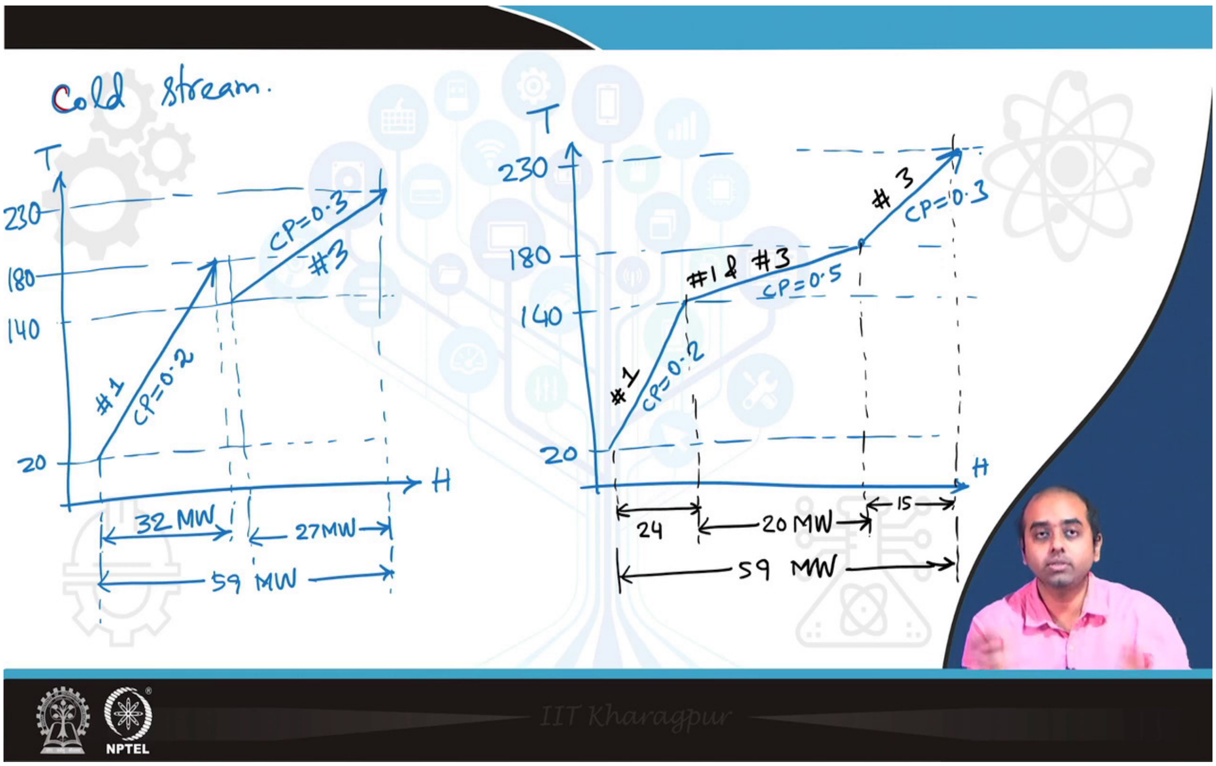

So, for the case of the cold stream I am not going to draw the individual curves I will draw straight away the cold I mean let me draw the cold stream first then it will make things more clear. So, in the case of the cold stream sorry I should draw in blue, it will make it better. Let us quickly draw the individual streams once again. So, for the cold stream you have the temperature zones as 20, then 140, 180 and 230.

So, there is this stream 1 which is having this temperature from 80 to it is being heated to 180. So, this is stream 1 that we are having and also stream 2. So, this is stream 2. For stream 2, it is from 140 to 230 remember. So, stream sorry this is not stream 2 this is stream 3. So, stream 3, stream 3 is the cold stream. So, stream 3 is essentially the reactor 2 feed and stream 1 is the feed to the first reactor, which is being heated from 80 to 180.

So, the CP value of stream 1 is 0.2 and the CP value of stream 3 is 0.3. So, the total, this amount of enthalpy provided by stream 1 is 32 megawatts and by whatever this stream 2 sorry stream 3 is around 27 megawatts, the total we are having almost 59 of megawatts that is required by the cold streams and both the cold streams together. So, now you can clearly understand from the inspiration of the hot stream that in between this zone from 140 to 180 the enthalpy is contributed by both the stream, stream 1 and stream 2 sorry stream 1 and stream 3 and the net CP is 0.5 in that part.

So, if I am supposed to draw the, this composite curve it would look something like this. So, again I have to make these demarcations. So, this is 20 let us say this is 140 is not exactly up to scale 180 and then we have 230. So, from this part we are having CP is equal to 0.2 and this part is like CP is equal to 0.5 that addition of 0.2 and 0.3 and this part we are having sorry this part we are having CP is equal to 0.3, is not it.

So, essentially this part is this part of enthalpy is contributed by stream 1, this part both by stream 1 and stream 3, and this part is only stream 3 which is providing the energy or the enthalpy. So, if I segregate these three parts. So, in between 40, 20 to 40 we need almost to heat that part 24 megawatts that is only required by stream 1, in between the temperature zone of 40 to 1, for 180 in fact there is energy requirement of 20 megawatts and this is needed by both stream 1 and stream 3.

And then in the temperature region of 80 to 180 to 230 we need additional 15 megawatts and this is needed exclusively by stream 3. So, total requirement stays the same it is 59 megawatts of energy. But now we see that how the I mean the composite diagram for the cold stream tells us that, what is the heat requirements, what is the heat requirements in the different temperature zone similar to the case of the hot stream, where we know that heat requirements in the different I mean the heat that can be provided or heat that is surplus and the different temperature zones.

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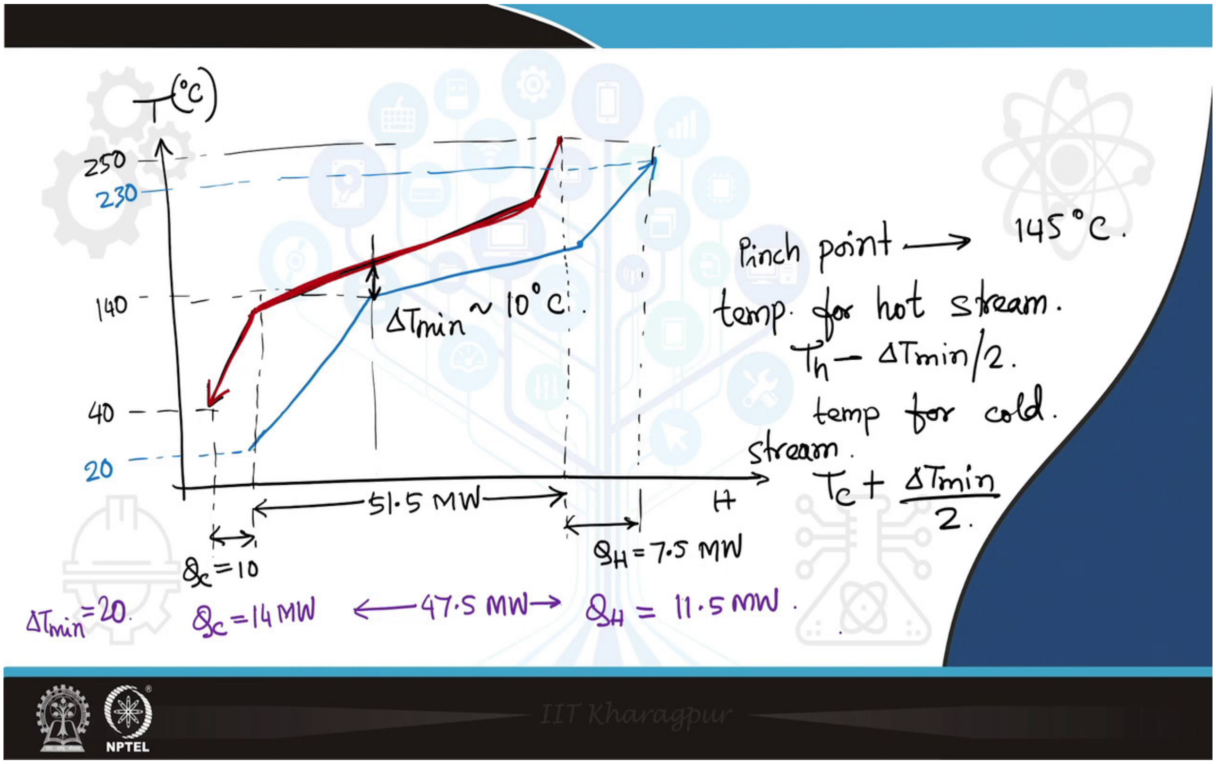

So, now the question is to I mean now the point is to I mean put this together the hot and the cold string. So, if I try to do together I am, I may not be able to draw it up to the scale but it will look something like this. So, the hot stream is like. So, this is the hot stream, if you recall this was the kind of shape where it started from almost the hot stream, started from 250. So, the highest temperature of the hot stream was 250 and it went down up to 40 degrees.

So, I should have drawn this in red sorry. So, this is the composite hot stream and the composite cold stream I just translate in the x-axis little bit and I see that this is almost like it looks like. So, the highest temperature for the this composite it is 230. So, this location is almost 230 and it starts from almost 20. So, this is how it will look if you draw according to scale. So, this is like putting both of these cards together.

Now, from this curve you can easily realize that this is the minimum point, I mean this location, this location is the minimum point where there I mean this is the point where the temperature and these two curves can touch. So, these two curves can touch only at this point I am not talking about the intersection. So, this is the pinch point. So, the pinch point is the temperature or is the value of the temperature where both of these two curves are and can intersect. So, that is the pinch point temperature I have intentionally drawn them separated out I have just translated along the x axis. So, that there is some difference between these two.

So, this is the pinch point or the point of the minimum difference between the two curves. So, essentially, we can say that this minimum difference at the pinch point should be at least 10 degrees because as for standard you recall for the single stream also we talked about in the same way. So, the minimum difference should be 10 degrees.

So, that is the pinch point. So, the pinch temperature and if you work this out this point the temperature at this point if you work this out closely it will be 140, that is the 140 temperature where the this starting of the that is the starting of the starting or the this 140 is the reactor 2 feed or stream 3.

So, the start the supply temperature of stream 3 is 140. So, that is the pinch point in this case. So, the pinch point temperature for I mean the pinch point temperature for hot stream is this T and whatever this 140, I mean this we have I mean the temperature corresponding to the I mean value. So, this is Th minus delta Tmin by 2 and for again pinch temperature for cold stream is Tc plus delta Tmin by 2. So, it is like raising this cold curve by 5 degrees and bringing down the hot curve by 5 degrees will give us the pinch temperature for corresponding for the hot stream as well as for the cold stream.

So, in this case you can realize that at the pinch point the hot side temperature, I mean the hot side temperature is 150 degrees, if we maintain a difference of 10 degrees, so it will be 150 degrees and the this temperature of the cold stream is 140 degrees. So, the pinch point is either you reduce the hot temperature by delta min by 2 or raise the cold temperature by these 5 degrees the relative min by 2. So, it is around 145 degrees is the pinch temperature in this case.

So, now of course from these grand composite curves you can easily also realize that what are the corresponding regions where the utilities would be needed. So, for this part you can realize that this whatever this part we have, so this zone where there is no cold stream you need a cold utility Q C of 10 megawatts similarly there is also a region here. So, where there is no hot stream available. So, you need a hot utility of around 7.5 megawatts and effectively the middle zone where a heat can be exchanged is 51.5 megawatts.

So, this tells us this satisfies the overall enthalpies in this case the total enthalpy requirement for the cold side was 59 megawatts and the total, so that is 51.5 plus 7.5 that is the cold side requirement and for the hot side requirement was 61.5 megawatts that is 51.5 plus the cold utility part which is another 10 megawatts. So, effectively in both the cold and the hot stream around 51.5 megawatts of energies can be essentially exchanged in this configuration.

So, in the next class, we are going to talk about that how this what are the conditions of this pinch and based on this what are the criteria that we can set for the network synthesis. One more point I must highlight here is that the delta T min here in this case we have chosen to be 20 10 degrees. So, if you increase the delta Tmin, which is if I mean, which will be good for the heat exchanger design because the capacity I mean it is area requirement will be less and the heat transfer will be more. I can increase the pinch I mean the delta T minimum to 20 degrees.

So, if you see if I increase it to 20 degrees, if the delta Tmin is increased to 20 degrees, the corresponding rise so if delta Tmin I can write it here itself if delta so far delta Tmin of 20 degrees, this zone of the Q C will be enlarged to almost 14 megawatts. The central exchange part or the energy that can be exchanged by heat exchanger would be 47.5 megawatts. And the cold utility sorry the hot utility in that case would increase from 7.5 to 11.5 megawatts.

So, you see as I increase my delta Tmin this is something which you have also seen in the case of the single stream situation the hot and the cold utilities increase and the effective, this heat that can be recovered or exchanged reduces. So, but at least delta Tmin of 10 degrees should be there be below that it is not a recommended practice for heat exchanger to function.

So, that is how it tells you that, if you increase your delta Tmin at the pinch point it will increase your cold and the hot utilities. So, all of you understood what the location of the pinch point temperature and the pinch point in the grand composite curve. In the next class, we will talk about the network synthesis, the criteria of the different of the pinch point, how we can estimate the pinch point using algorithm or a calculation strategy and then from there we will see that how the network can be synthesized.

So, as to optimize the total energy that is available in the system between the streams. I hope all of you like this lecture on the grand composite curves and from there we get an idea about the pinch point which is necessarily not the lowest possible temperature in the cold side which is the case for single stream. So, when you have more multiple streams this (com) I mean the pinch point becomes more and more crucial in the system. Thank you for your attention.