Mathematical Modelling and Simulation of Chemical Engineering Process
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Lecture 42
Heat exchanger network synthesis

Hello everyone, in this class we are going to talk about the calculation strategy apart from that graphical method, what is the strategy to in estimating the pinch point temperature, and then we also talk about the heat exchanger network configuration, and how we can synthesize from the pinch point temperature.

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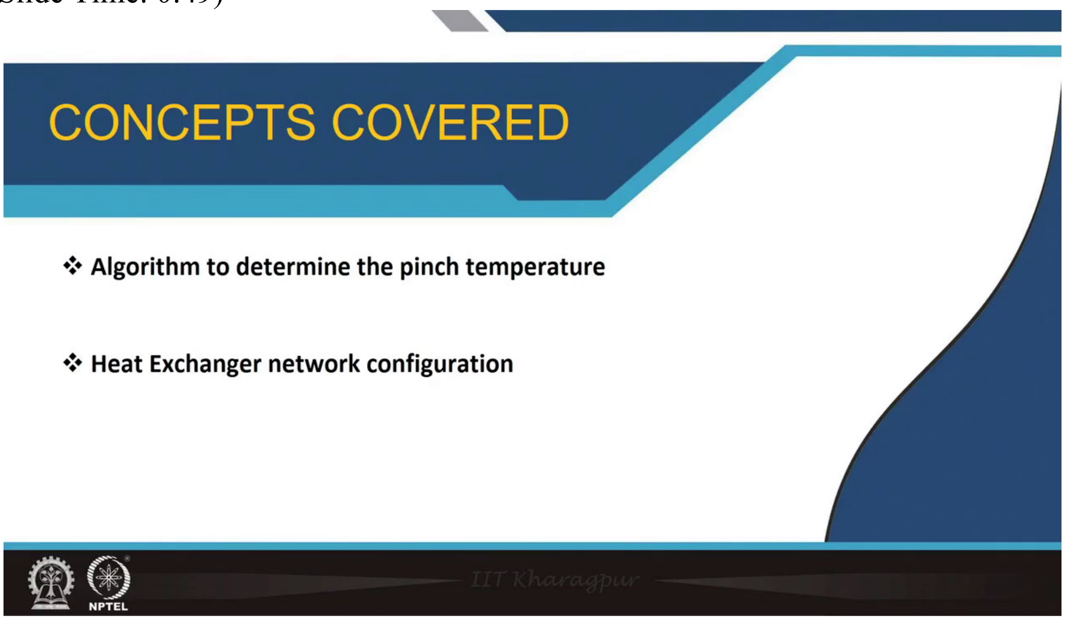

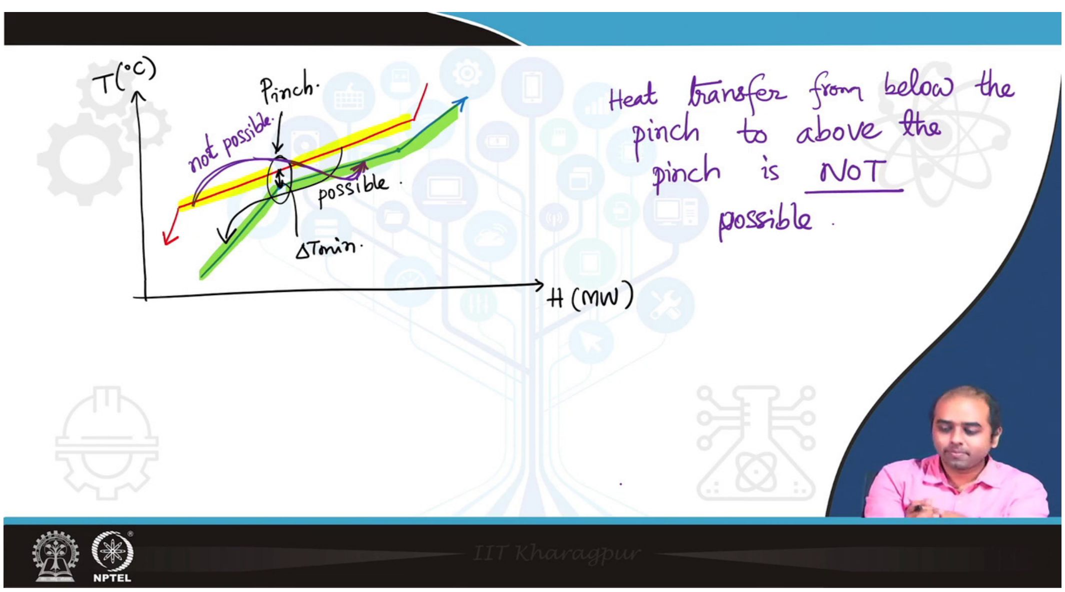

So, if you recall in the last class, we talked about the thus 2 hot and 2 cold stream. So, let us just start from there and let me tell you the conditions which needs to be always satisfied at the pinch, so that you do not violate the energy conservation principles or the laws of the thermodynamics in fact. So, this was the kind of the hot curve.

So, the hot curve was something like this if you recall and then the kind the sorry, so this was the cold curve, is not it? And then we said that this is the pinch location this is the pinch location. So, now please realize that the heat transfer from the zone above the pitch to the zone below the pitch is possible. So, from, so this is, so if I try to demarcate the zones. Let us say this is the zone on the hot side above the pinch and this is the zone on the cold side, sorry on the hot side below the pinch, sorry yes, and then this is the zone below the pinch in the cold side, and this is the zone above the pinch in the hot side.

So, always the transfer of energy from above the pinch to below the pinch is possible this is possible. So, this is from above the. So, this is the pinch location. So, from above the pinch and this is our delta min this is possible from above the pinch to below the pinch is possible. But the other way around that is from this side to this side is not possible. So, transfer of energy from the hot to the cold stream is possible across the pinch from the higher hot side to the lower cold side, from above the pinch to lower the pinch but from lower the pinch to above the pinch is not possible that will violate the this energy the laws of the thermodynamics in fact.

So, always it is a recommended practice that you try to match the energies or try to exchange the energies available in one side of the pinch. So, whatever (temp) I mean these streams that we are having or whatever temperatures we are having above the pinch you match it with the respective hot and the cold stream. Similarly, whatever temperatures are and streams are available below the pinch you match the corresponding hot with the cold and the cold with the hot.

If you want to make a connection across the pinch then make sure that it is the temperature is I mean of the hot stream that you are choosing to exchange should be above the pinch that can be utilized to match the stream, the cold stream which is below the pinch and not the other way round, by the way round I mean you cannot match a hot stream which is below the pinch on the hot side to a cold stream which is above the pinch.

So, at this moment this looks very obvious because looking into this picture it tells you that this this violet color that I have drawn, whatever I have written not possibly at a lower temperature compared to the cold stream but when you have more than 5 or 10, it is a cold and 10 hot streams this may not be so trivial and may not look obvious. So, this is a criterion that you have to maintain. So, that heat transfer I should write it down. Heat transfer from, transfer from below the pinch, from below the pinch to above the pinch is not possible, you cannot violate this condition.

So, this is something always to be remembered when we are trying to match the streams and the possible energies available in that part. So, the streams I mean the streams below the pinch you can consider them to be sort of like heat source and above the pinches like heat sink. So, you cannot transfer heat from the below the pinch to above the pinch that is something not possible.

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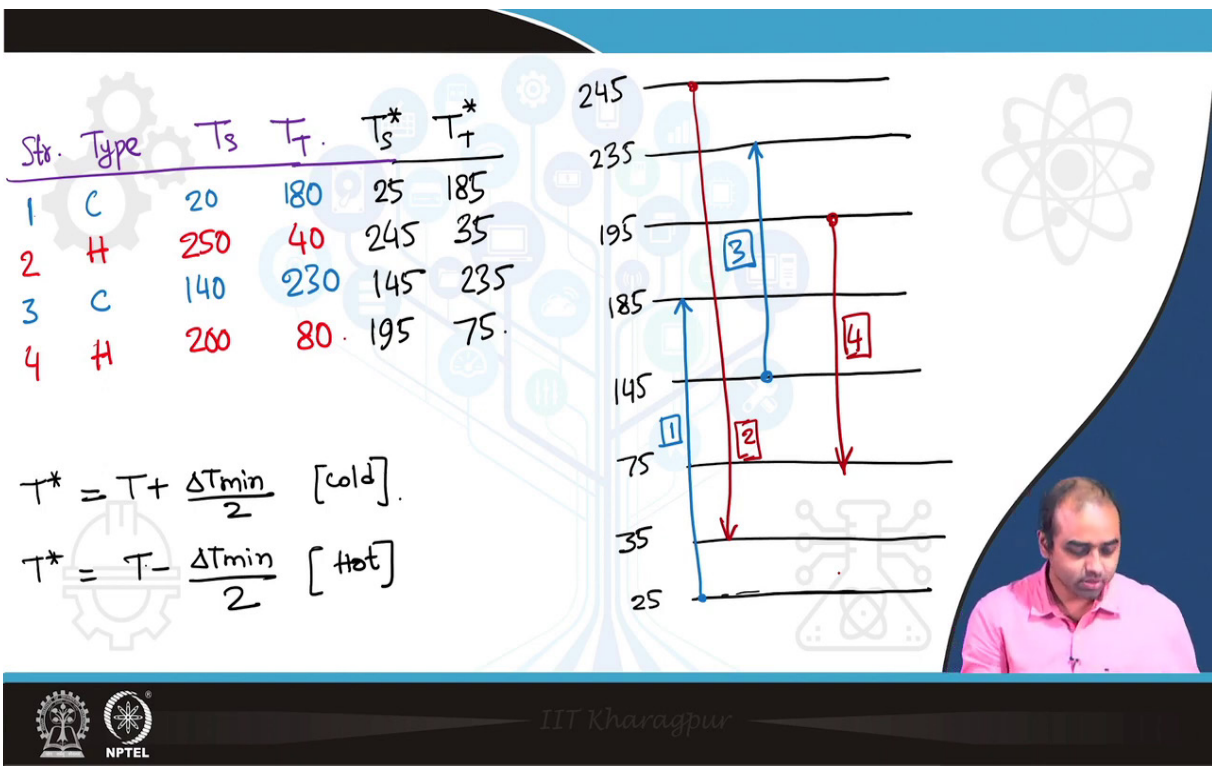

So, now let us look into the algorithm or the calculation strategy apart from the graphical method based on how we can estimate this pinch temperature. So, let us write down the stream identities once again and they are types and T s T T value sorry T T values. So, you have stream 1, stream 1 type is cold it is from 20 to 180 and we have stream 3 as cold which is from 140 to 230.

Similarly, stream 2 is a hot type. So, that is from 250 to 40 degrees and stream 4 is again a hot stream that is from 200 to 80 degrees.

So, now also let us try to evaluate the if we raise the temperatures for the hot stream and the cold stream respectively by delta Tmin by 2. So, T S star which is like for the cold stream it would be let me write T star for the cold stream it is T plus delta Tmin by 2. So, this is for cold stream and for a hot stream we are reducing the temperature by delta Tmin by 2, it is just to bringing down the top curve 5 degrees below and raising the this cold curve by 5 degree. So, that at the pinch point they should touch each other considering that we maintain a gap ideally for these 2 curves to be as 10 degrees.

So, under those circumstances if I raise it by delta T min by 2 the cold curve and reduce the relative mean by 2 lower the height of the hot curve then they should match at the pinch point and essentially at the pinch point the net energy that can be transferred or the net energy in the reserve should be equal to 0 we will talk about that. So, let us work out the corresponding numbers here. So, this will be 25 and this would be 185. So, we are raising them by 5 degrees. So, this is 245 and this is 35. So, reduce lowering them this is 145 and this is 235 and this is 2 sorry 195 and 75.

So, let us try to draw or prepare a table marking these individual temperature zones corresponding to T star values. So, something like this let us say this is one line for the lowest possible is 25. So, all the temperature intervals we are trying to draw here it need not to be according to scale no issues on that then you have another one 35, then we have another one at 75, then another one 145, all the temperature intervals then 185, then 195, then you have 235, and 245.

All the temperature intervals I have drawn now. Now, here you try to mark the different streams, the hot and the cold streams all the four streams you can mark here. Maybe I should have drawn it in the next page but anyway we will try it here. So, the first stream is from 25 to 185. So, this is stream 1, I mark it as stream 1. So, this is one cold stream that is increasing the temperature from 25 to 185 and then we also have stream 3 that is from 145 to 235. So, this is stream 3.

So, I can also draw similarly for the hot and the cold ones sorry the hot ones the hot is a stream true that is from 35 to 245. So, this is the biggest one. So, this is stream 2 and also, I have stream

4 from 195 to 75. So, next is to use this curve and then talk about the different write down the temperature difference of these intervals write down the effective CP values, write down the effective delta h values and then note whether its deficit or surplus. So, we will use this curve in the next slide.

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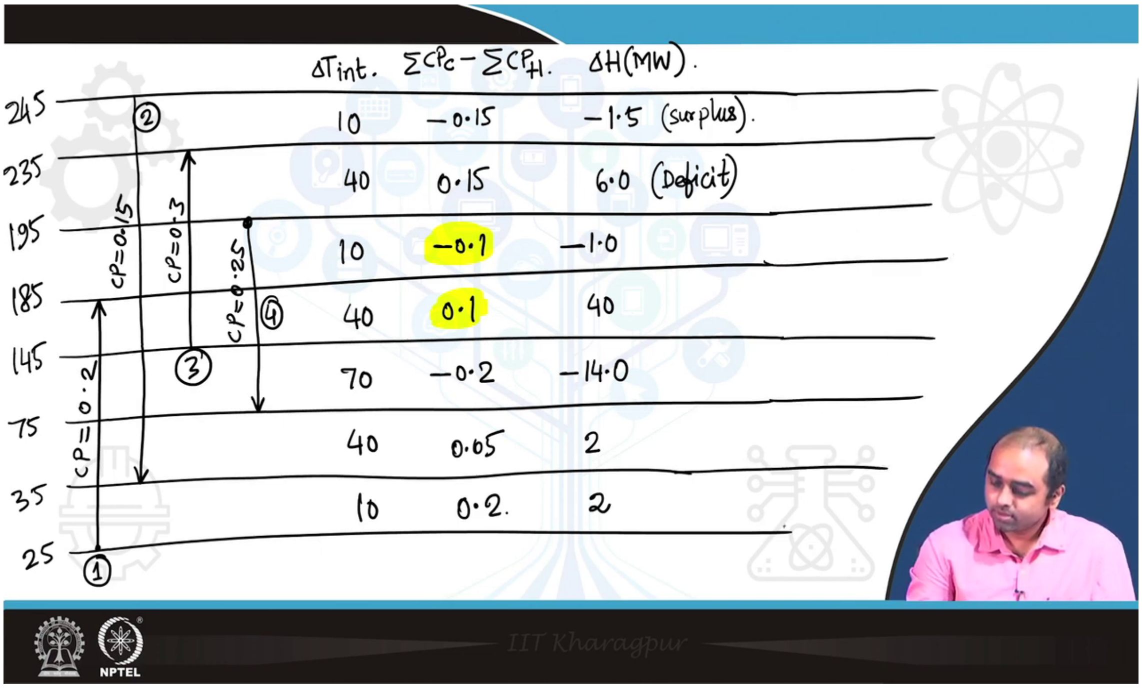

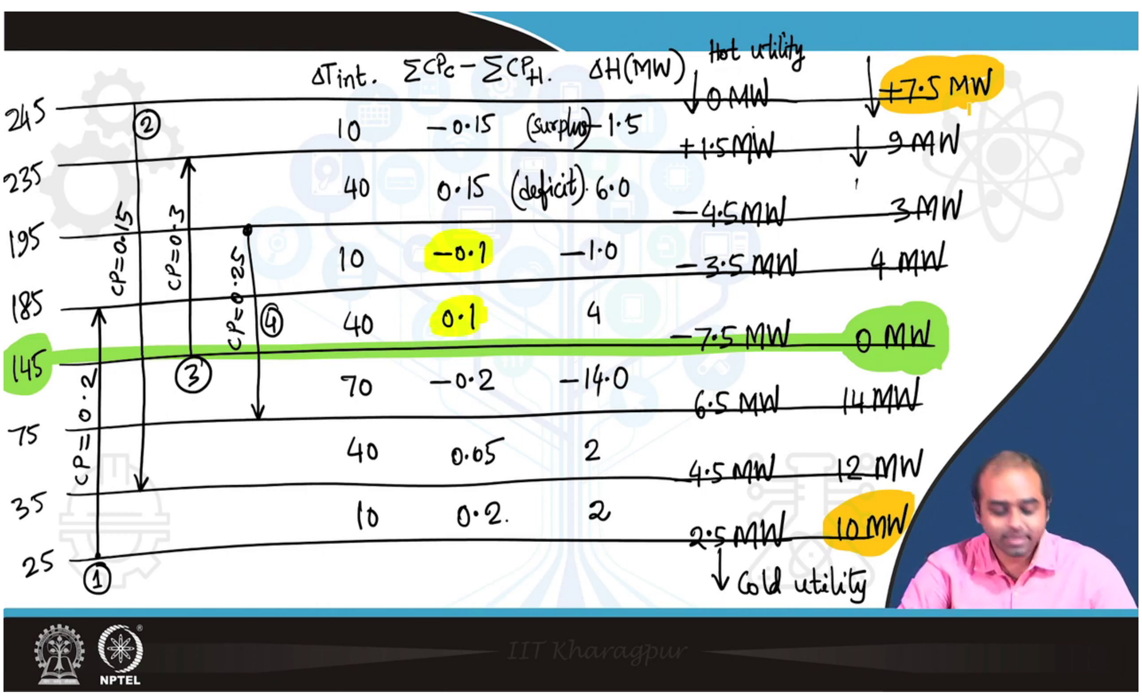

So, just let us quickly draw it in the next slide or why not we will quickly draw it. So, this is the 25 or maybe this is the 35, I draw one more below 25, 35, then we have 75, then we have 145, then we have 185, 195, 235, and this is 255. So, we have one stream from 25 to 185. So, this is a stream number 1 and I write down the CP values as 0.2 for this case, then there is another stream from 35 to 250 sorry 245. So, this is the hot stream the CP value is 0.15.

So, this is stream number 2, then I have stream number 3, 145 to 35, the CP value is 0.3 for this case then another one is 195 to 75, CP value is 0.25. So, if I try to write down the delta H of the different in the intervals. So, this is 10 degrees, this is 40 degrees, then I have 10 degrees again, then 40 degrees, then 70 degrees, then 40 degrees, and finally 10 degrees effective CPc. So, sigma of the cold side CPc minus sigma of hot side CPc. So, this is the net CPc for this temperature zones and we mark them plus and negative accordingly.

So, for the first case in this temperature zone, it is minus 1.5. Because that is the part of the hot stream this is plus 0.15, then we have minus 0.1, then plus 0.1, minus 0.2. So, the net CP's net CP is values. So, CP of the cold stream minus the CP of the hot stream net CP of the hot stream that is why I wrote sigma.

So, when I write let us say for this case let us say for this case when I am writing I am essentially taking into account of the CPc of only one cold stream that is 0.3 and then minus of two hot stream 0.15 and 0.25. So, total net hot stream is 0.4. So, 0.3 minus 0.4 gives you minus 0.1 similarly is the case here there you have four CP's one is for I mean 2 for hot stream and 2 for cold stream. So, for the cold streams you have 0.2 and 0.3 this net is 0.5 and for the hot stream it is 0.15 and 0.25.

So, it is I mean resultant is plus 0.1 and here I have point 0.05 0.2. Now, delta H in terms of megawatts in each of these temperature intervals. So, the minus represents it is a surplus. So, minus represents it is surplus or excess heat into this system and positive represents it is deficit because positive means it is the heat requirement by the cold stream to heat it up, that is why it is deficit, that is the general nomenclature based on the heat of reaction, heat of reaction is negative it means exothermic.

4 and I hope all of you get how I am getting this delta H. So, it is multiplying the delta T interval with respect to the net CP. So, if I multiply I am getting the delta H in that corresponding

intervals 40 this is the highest minus 14. So, this is 2 and this is also 2. Now, please realize that if in this case I also extend this little bit more we can use this. So, if I am having plus deficit. So, initially let us say this from the hot utility or from a hot source I am trying to find out what is the net energy content or the net energy reserve for this system.

So, in that case I, if I start my base value or the base heat level for this system let us say I am starting with 0 megawatts of energy in a system. There is no external heat supplied. So, I have 0 megawatts of energy. So, from there if I supply this delta H amounts of heat which is a surplus heat to my energy container or to my energy reserve, I will be getting 1.5 megawatts of energy, after supplying of 1.5 the surplus will be added to my energy reservoir.

Now, from there if I take out another 6 megawatts of energy. So, I will be left with minus 4.5 megawatts of energy to that again I add 1 megawatt because this is the amount that is released. So, it will come to minus 3.5 megawatts, and sorry this is not 40 this is 4, to that if I again take out 4 megawatts of energy I will be left with I mean the energy content would again further reduce down to minus 7.5 megawatts, to that now I add plus 14.5 plus 14 megawatts of energy because that is the surplus I am in adding to this energy reservoir.

So, my net energy content status into 6.5 megawatts. From there again I take out 2 megawatts of energy, again 2 megawatts of energy. So, ultimately, I will be, so at the top side it is the hot utility, which is applying the heat maybe and here I am getting into the cold utility. Because this is the net energy content that is present at the end of the system if I start with energy content energy, supply of 0 megawatts into the system into my system.

Now, let us say if I try to say, from here you please identify what is the you please try to identify that what is the maximum value of this energy in the reservoir that I am getting at any point of time. So, all these megawatts of energy is getting transferred across this temperature intervals. So, what is the amount of energy that is get is the minimum condition.

So, the minimum that I am getting is minus 7.5 as the energy status of the energy content and we all know that energy content cannot be negative. So, it can be zero. So, as to supplement that minus 7.5 from the starting, let us say I can supply 7.5 megawatts of energy from the starting the base state of my reservoir is 7.5.

So, now correspondingly this energy at this second as it moves to the interval of 235 the energy content becomes 9 megawatts, in my system. Then further it as it from there if you take out this minus 4.5 whatever I mean sorry this from there you are actually taking out 6 megawatts of energy is not it. So, this is then 3 megawatts of energy.

So, the easy way is to just add 7.5 megawatts to all the values but at least if you do understand and then do from 3 then again you take out 2 megawatts of energy from there you sorry from 3 you add 1 megawatt this minus 1 is added. So, it is 4 megawatts now you have from there you take out 4 megawatts. So, it is 0 megawatts that is the idea that we initially said he will add 7.5 megawatts. So, that the minimum energy status would be 0 megawatts. So, from 0 next is you are adding 14 megawatts. So, this energy is content would be 14 megawatts from there you take out 2 megawatts and again 2 megawatts of energy.

So, the energy where the energy content is zero megawatts that is the point you realize that is the point of the pinch temperature. The energy corresponding to zero megawatts of energy is the pinch temperature. And also, from this calculation you find out that this the whatever the value is written at the top and at the bottom whatever we received these are the corresponding theoretical possible hot and the cold utilities.

So, 7.5 megawatts of this hot utility need to be supplied at the, this highest temperature side or to cool down the hot stream. And similarly, on the cold side or the to heat up the cold streams at the lower temperatures you need around 10 megawatts of energies. So, these are the corresponding hot and cold utility limits or the values that is required.

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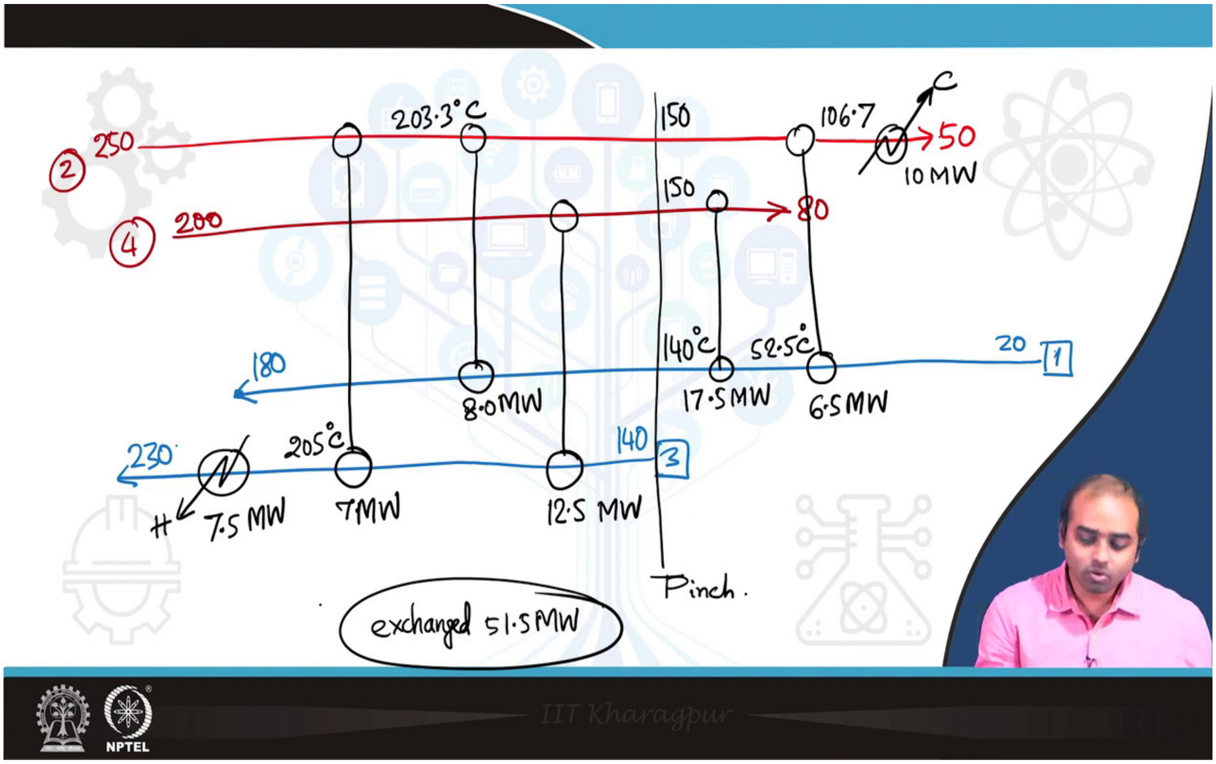

Now, coming to the network design. So, before we go to the network design some heuristic guidelines that I would like to specify here. One is that you have to satisfy the pinch condition at the pinch criteria that energy transfer or balancing streams with energy transfer from below the pinch to above the pinch is not acceptable and it cannot be violated.

Second is that we should try to utilize the streams for energy exchange which has lower delta H values completely as far as possible. Third is that avoid adding utilities to the hot or the cold stream I mean, let us say for the hot stream avoid adding cold utilities to the hot stream above the pinch temperature. Then the cold utilities becomes I mean it is too loaded up, it is too loaded up.

Similarly, you avoid adding utilities to the cold stream below the pinch that is that is not something very desirable. So, for the hot stream avoid adding utilities avoid adding cold utilities above the pitch and for the hot stream avoid adding any utilities below the pinch. And the idea is that the cold and the hot utilities should always be used at the extreme lower most and the higher most temperatures. So, with this idea let us try to write down this try to make this balance.

So, if you see I draw the hot streams at the top that is generally the convention. So, let us say this is my hot stream. So, it is from, so the idea is that you draw a big line representing a temperature from let us say from 250 to 40 sorry for 40 degrees and similarly another one a little bit lower, this one is another stream. So, this is a stream 2 and this is a stream 4 this is from 200 to 80 degrees, and let us also draw the cold stream in the same diagram something like this.

So, this is stream number 1, it starts from 20 degrees to 180 degrees and then we have stream 3, which starts from 140 degrees to 230 degrees and this is the pinch sorry this is the pinch temperature line, let me draw it here. So, this is the pinch zone or the pinch point zone. So, correspondingly for the hot side pinch temperature is 150 and for the cold side it is 140. So, the as I said the idea is to utilize the streams which has lower CP values completely.

So, with this idea, first we are trying to match, first we are trying and the best way to match streams is to do not jumble streams from across the pinch we should always try to utilize them from the on one side of the pinch. So, whatever we are having here. So, this is 140 150 degrees for the hot side and it is 140 degrees for the cold side. So, we are we do not want to mix from below and above the pinch. So, for example I am saying that below the pin. So, a heat transfer from the hand side of the red colored streams cannot be used to heat something on the left-hand side of the cold streams, that is a violation of the pinch principle.

So, this stream, stream number 4 that we have that is extending from 150 to 80 that has energy of almost 17.5 megawatts. So, this is the connection I can make from here to here. So, this will be a stream of 17.5 megawatts of a heat exchanger and this will completely utilize the hot stream whatever energy is there. Similarly, for the I mean now the remaining part, so after this the temperature that remains is 52.5. So, from 52.5 if I completely utilize up to 20 degrees. So, I have to connect it with this exchanger here.

So, this exchanger would be of 6.5 megawatts you can work out the corresponding values delta H values and the temperature after this. So, let me draw this sorry. So, after this the temperature from 150 in this stream 1 drops down to 106.7. So, to reduce it to 40 degrees you need a cold utility. So, cold utility is around 10 megawatts of energy is required in this cold utility. So, this is how we are making the full balance or full utilization of the cold stream essentially that we see, of course there could be other possibilities of the matching but this is of course one of the possibilities below the pinch which is something we can do.

Now, it is the term for the sorry I called stream I should always write like this. So, now is the time for the matching on the above the pinch side. So, first easy way to do is let us utilize this stream for this stream 4 if I recall correctly stream 4 has the lowest CP value. So, stream 4 has the CP value of if I go back, so, stream 4 has the CP value of 0.25. So, I can utilize if you see correctly that from 150 to 200 and this stream 4 can supply around 12.5 megawatts of energy. So, let us say that I mean I can connect it to the stream here stream 3 and this would be like completely utilizing stream 4.

So, stream 4 does not need any cold utilities on either side it can be completely utilized up. Now it is the part of the, this top stream. So, one of the combinations we can make from here to here. So, that will utilize completely the energy available with stream 1 up to 180 degrees. So, after making this change the temperature after this would be 203.3.

So, to this I have to make another connection I mean there is a possibility I can make another connection with this two here. And this exchanger would be of 7 megawatts and the temperature of this stream would rise up to 205 degrees. So, after that it is not possible to heat up to 230 degrees because that is completely used up, I mean whatever the energy is available is completely used up of the hot stream of temperature this second stream.

So, here I can I will need a hot utility. So, the hot utility of 7.5 megawatts. So, you see that here I am adding a hot utility of 7.5 megawatts and here I am adding a cold utility of 10 megawatts respectively on the hot stream and here respectively on the cold side stream because that much amount of energy cannot be exchanged.

So, you if you add all the possible, I mean all the values you will see that we are getting exchange we are getting the possible exchange here out of this heat exchanger network configuration that we have drawn here in this case the total amount of energy that we can exchange is 51.5 is exchanged energy is 51.5.

So, this is the theoretically maximum possible amount of energy that can be exchanged and we made a combination where the maximum energy can be utilized. So, since this was a case for 2 streams and 2 hot and too cold stream this was I mean easily we could do but for multiple streams this is a problem of an optimization and essentially a linear optimization problem where you need to make the appropriate connection. So, that the total amount of exchange of the energies is maximum as far as possible and the hot and the cold utilities loads are reduced. So, with this connection you can also try to draw the flow sheet of the optimized network.

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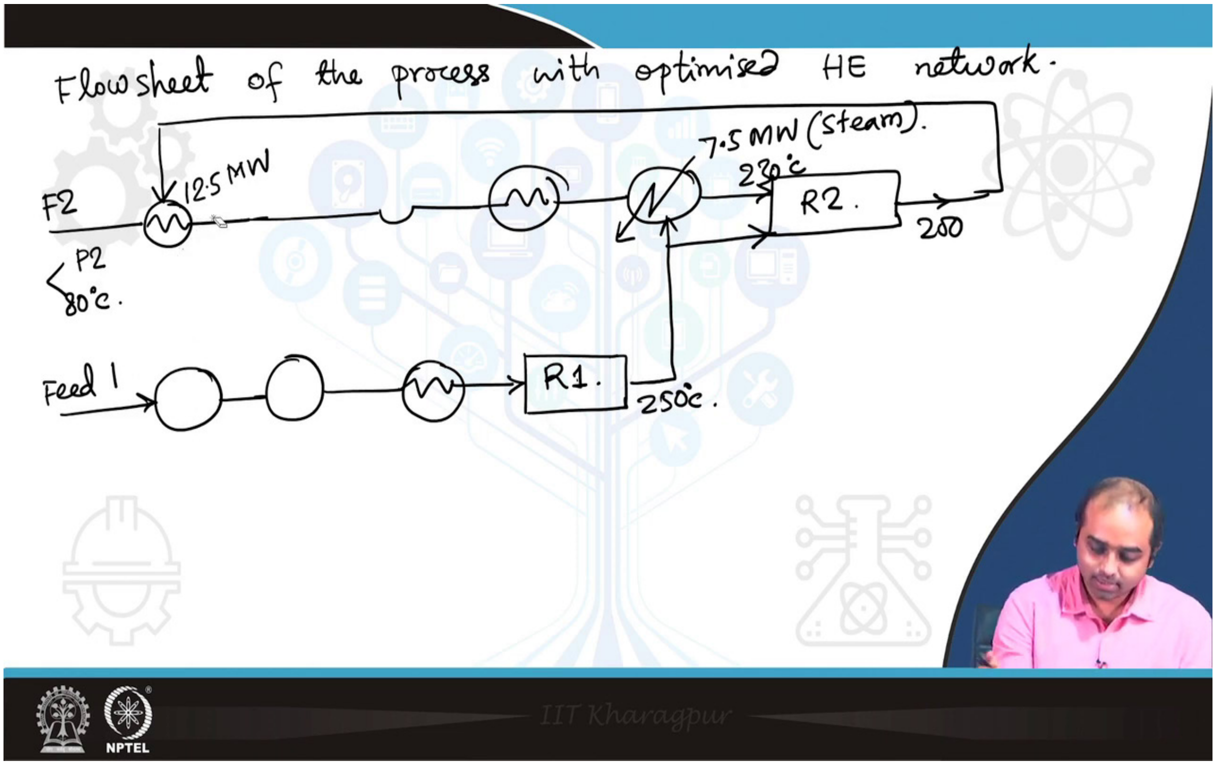

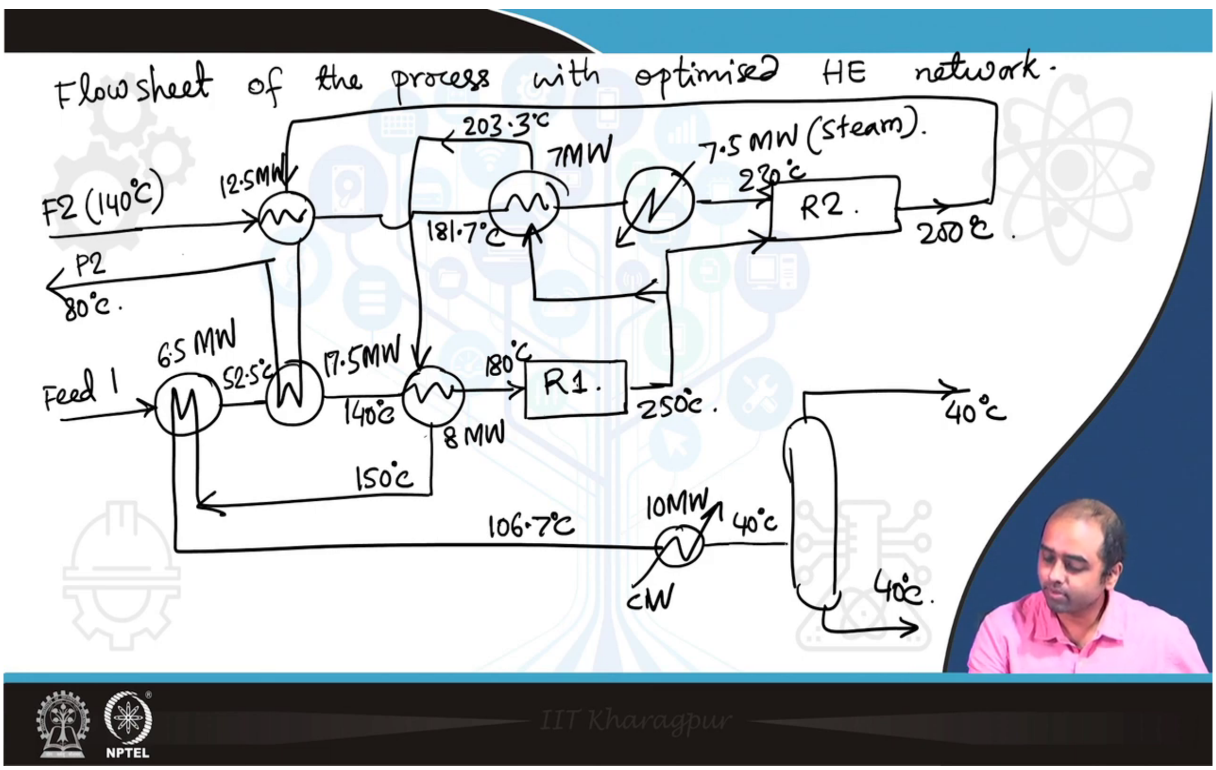

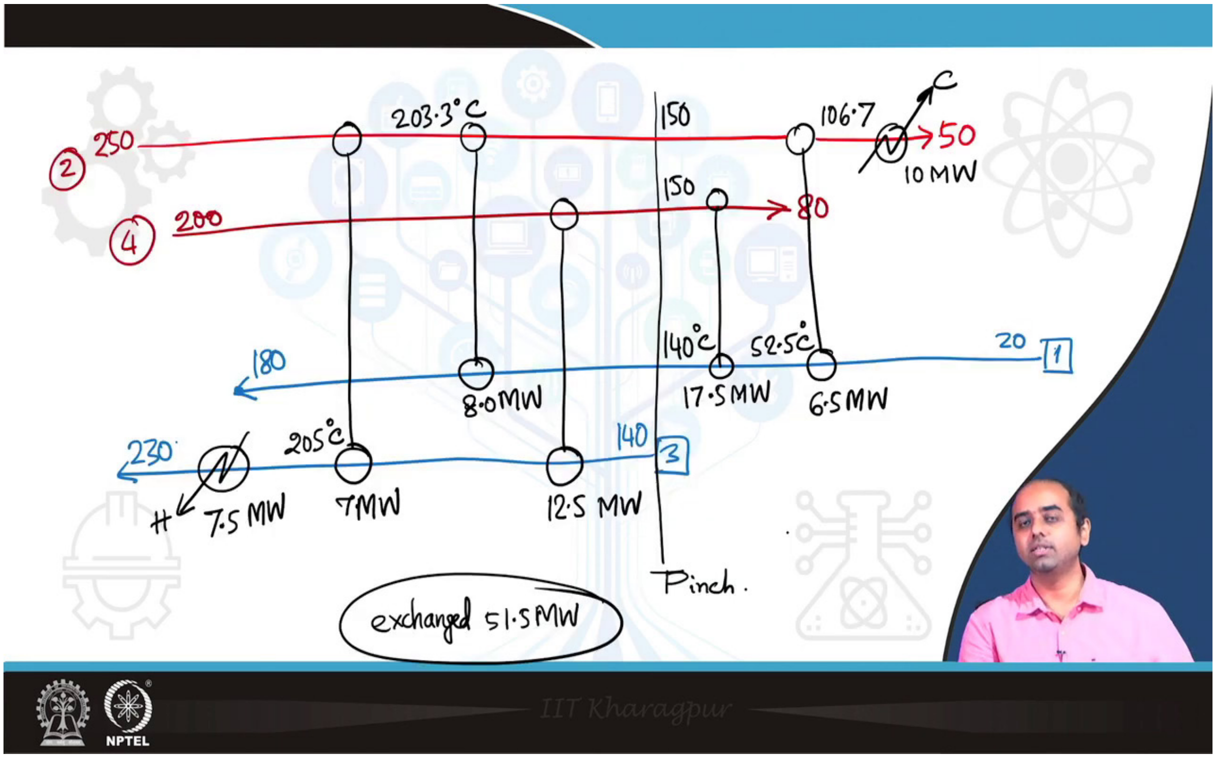

So, let me also try to do that here. So, the flow sheet of the optimized flowsheet of the process, flowsheet of the process with optimized heat exchanger network with all the streams etcetera. So, when the stream 1 that is coming. So, this is a feed 1 if you recall. So, this is now fast is connected to an exchanger. So, please just follow this this is another exchanger and then it goes again it passes through another exchanger and then it goes to reactor 1. So, feed this is reactor, let me write it at R1 reactor 1. And what are these exchanges will immediately talk about now but let me first draw feed 2 also.

So, this is one exchanger, it is passing through then again there is a bifurcation of the line because something is coming from here on this side sorry not here, here again it is passing through an exchanger and finally it is the sorry the hot utilities of 7.5 megawatt, let us say this is steam we are supplying and then it is going to. So, it is going to reactor 2 and this stream is going there as well as going to reactor 2. So, the outlet is 250 degrees here the inlet is 230 degrees and whatever the reactor 2 we are getting at 200 degrees this is exchanged back to here, which is then again so this is an exchanger of 12.5 megawatts, which is again exchanged here and sent back sent out as the product.

So, the R2 stream is not going straight up into the product instead it is using reused to reheat the feed. So, this is product 2 and the exit temperature is 80 degrees. Sorry I think I made a mistake, sorry this is the mistake here, this exchanger is not here this this actually goes to this part. So, let me draw it clearly. So, this is exchanging with this reactor then it is going out. Similarly, the stream that is going through here sorry it is going not here coming here, so this exchanger is of 7 megawatts after this thing I mean the temperature is 203.3.

So, from 250 it is reduced to 203 and this one, this is fed to 180 degrees. So, before that there is this heat exchanger. So, this exchanger is of 8 megawatts and the temperature after this stream reduces to 150 of course this is a hot stream and this exchanger was 17.5 megawatts, and after this this is of 6.5 megawatts, after this the temperature is 52.5 degree centigrade, and this becomes 140 degree centigrade, this after this exchange 150 degrees reduces to 106.7 degree centigrade and this becomes sorry this is a cooling actually.

So, this is cooling water and here you exchange and this capacity is 10 megawatts and it goes to 40 degree centigrade and it goes to into the separator, if you recall that is the separator, we had of 40 degrees. So, this is the complete, this one is of 12.5 megawatts of this exchanger. So, this is the complete network diagram based on this configuration, how the streams are connected is also part of the process flow diagram and this will give you a good glimpse about the connections of the different stream, and how you are reutilizing the reactor product streams to preheat your feed essentially, that is the major idea that you see in this heat exchanger network configuration, and this is something which we have drawn based our network configuration that we have shown here.

So, I hope all of you liked this lecture, in the next few classes we will talk about process simulator known as Aspen plus, where we will see that how different units – separators, heat exchangers, reactors can be connected in series parallel in a network, and how the calculations can be done there. Thank you and see you in the next class.