Heat Exchangers: Fundamentals and Design Analysis
Prof. Prasanta Kumar Das
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 62
Heat Exchanger Network synthesis

Hello friends, we had a journey, we had a journey in the domain of Heat Exchangers. We have started from the Fundamentals, we have seen different types of Heat Exchangers, we have discussed what are the basic engineering principles of analysing Heat Exchanger, their application, different types of Heat Exchangers. Other attributes like fouling etcetera.

So, all these things we have decided, sorry we have discussed. At least, to a basic level we have discussed all these issues. Now, we have come to the last topic of this particular course Heat Exchanger; Heat Exchangers Fundamental and Design Analysis.

So, this topic is Heat Exchanger Network Analysis by Pinch Technique. Let me give you some background. This is a topic, closely related to Heat Exchangers though not exactly the design of Heat Exchanger or Analysis of Heat Exchanger, but we thought that, this is an important topic which the person who like to have a general appraisal general overview of Heat Exchanger should be aware off.

So, that is why we have included this topic. Now, what is this all about? It is like this that a single heat exchanger is very important. It is analysis thermal design, hydraulic design, mechanical design, integration with the other components of the plant or the system that is very important.

But when we think of a plant or a system particularly there are typical process plants chemical process plants refineries, petrochemical, processing units, pharmaceuticals in power plant power generation. So, where we use a number of heat exchangers or number of equipments dealing with energy exchange.

Now, in that case, how we should have some sort of interconnection between the heat exchangers. So, that is actually Heat Exchanger Network Analysis more of it will be clear as we proceed. Now, for this the of course, on this topic there are, it is very important for, chemical engineers process engineer plant engineers. It is very important.

There are a number of books etcetera on, Network Analysis Heat Exchanger Network Analysis. Sometimes it is called process integration or heat integration of a chemical process plant, but what I have done, we cannot devote much time because, we have devoted on many, aspects of Heat Exchangers.

So, we want to be bit precise on this topic as we have done for other topics also. We have taken most of the material from a reference. It is given, in the title slide it itself the, pinch design, method for Heat Exchanger Network by B. Linnhoff and E. Hindmarsh Chemical Engineering Science Volume 38 and, number 5. So, the reference is given; so, in, the year of 1983.

So, this is the Pinch Technique, actually it is almost at that time in late 70’s, 78 79, the Pinch Technique came. Before that also, there were some method for Heat Exchanger, Network Analysis heat integration or, process integration, but this Pinch Technique is one of the very strong technique. It is I do not like to say that this is the only technique for Heat Exchanger Network Analysis, but this is one of the comprehensively used technique and at least let us have some idea regarding Heat Exchanger Network Analysis. So, for that one of the standard method like Pinch Technique I like to introduce

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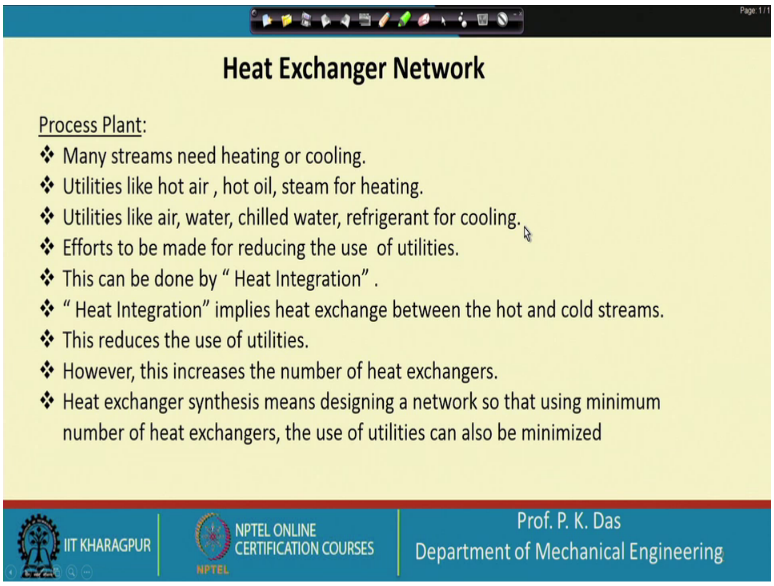

Next slide, Heat Exchanger Network. What is a Heat Exchanger Network? Consider a Process Plant Many streams needed heating or cooling. Let us say a petroleum refinery where we have to go for fractional distillation. So, certain streams are to be heated and certain streams are to be cooled and large number of streams are to be heated large number of streams are to be cooled.

How the heating and cooling can be done? There could be Utilities. Utilities like hot air, hot oil, steam those could be used for heating; Utilities like air, water, chilled water, refrigerant etcetera those could used for cooling. Let us say the entire cooling need for a Process Plant. We will supply only by utilities, there could be number of Utilities and with that we will satisfy all the cooling needs

Similarly, all the heating needs let us say in this plant we are going to satisfy with the help of hot Utilities. So, that amounts to a very large extent of energy usage. Instead of that, efforts to be made reducing the use of Utilities this can be done by Heat Integration Heat Integration implies heat exchanged between hot and cold stream. Hot stream I mean some stream are to be cold streams are to be heated and hot streams are to be cooled.

So, now, if we can do it mutually the heating and cooling that can be done mutually between the streams so; obviously, from outside we need not have, that much of energy utilization. So, our operating cost will reduce.

So, this reduces the use of utilities means this reduces the operating cost; However, this increases the number of heat exchanger so; obviously, when we like to do this. So, probably we need to have more number of heat exchangers. Heat Exchanger synthesis means heat exchanger network synthesis it should be Heat Exchanger Network synthesis means Heat Exchanger Network synthesis it should be it was Heat Exchanger Network synthesis means designing a network.

So, that using minimum number of heat exchangers the use of utilities can be minimized. So, we want to do two things of course, the first goal is to minimize the use of utility. So, running cost energy will be concerned and running cost will be minimized. So, this has got; obviously, lot of benefits not only direct benefits; it has got also indirect benefit.

Direct benefit means, we are we are, we are generating more energy sorry we are, using more energy, internally. So, our demand on fossil fuel sources of fossil fuel that will get reduced that is the direct advantage indirect advantage is that when we are using lesser amount of fossil fuel the degradation of the environment will be minimum; the degradation of the environment will be minimum.

So, this is my second achievement, and. So, that is the first goal our first goal has got two achievement. The primary achievement and secondary achievement; then, the second goal of the Heat Exchanger Network synthesis is that I will try to minimize the, use of utility, but I will do it with minimum number of Heat Exchangers.

So, number of Heat Exchangers that gives the initial cost. So, the initial cost also I would like to reduce not only I will reduce the, running cost I will protect the environment. I will also try to reduce the initial cost. So, you see Heat Exchanger Network synthesis has got a very profound goal. In today's scenario this is very important why in today's scenario years together no Process Plant or chemical process plant for that matter has been designed with without a some sort of consideration to heat integration or process integration where, Heat Exchanger Network Analysis is a part is a very important part. So, with this let us go to the next slide.

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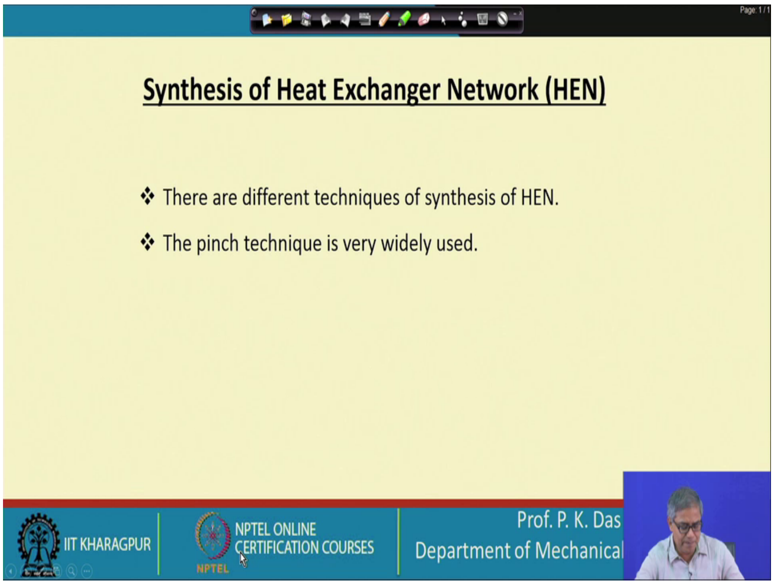

Synthesis of Heat Exchanger Network, Heat Exchanger Network is commonly known as H E N. There are different techniques of synthesis of H E N; the Pinch Technique is very widely used. There are different techniques, but we are using Pinch Technique. So, one have to remember that, basically what we are dealing with is an optimization problem we are trying to minimize or maximize something.

So, this is a an optimization problem there are many constraints particularly, particularly, when we are, taking a practical power plant sorry practical process plant. The plant is very large and there are many many constraints very conflicting constraints are there in many cases. Suppose, one constant will have one effect or, the other kind of other constraint will have almost the reverse kind of an effect.

So, those situations are there. So, basically we are trying to do solve an optimization problem. Now, in the, in the present course of course, we will keep the problem simple, but you will get some idea that what is the issue and what could be the demand in a in an industry as far as this process integration is concerned, sorry the Schematic representation of a Heat Exchanger Network.

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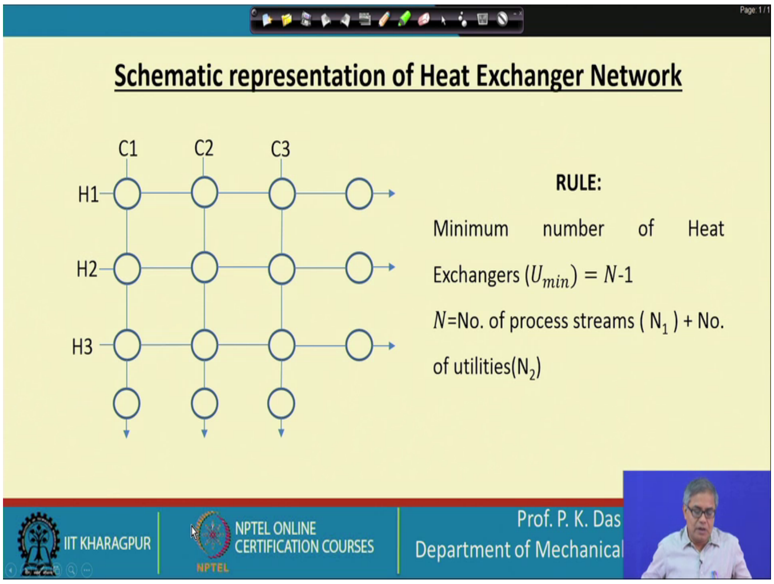

So, you see C denotes cooling stream ,and, number of cooling stream. There are three cooling streams like this and H denotes heating stream. So, there are number of heating stream like this. So, one hot stream or H 1 is to be cooled. So, H 1 is having initially a high temperature I have to bring it to a low temperature what I can do?

So, there are many cold streams available which needs to be heated. So, we can have some mutual Heat Exchange between H 1 and C 1, H 1 and C 2, H 1 and C 3 by these three Heat Exchangers, but that does not bring the stream H 1 to the target temperature.

So, ultimately what we have to do at the end I need to have a cooler and from there I will have the required temperature. So, minimum number of Heat Exchangers that is U min that is equal to N minus 1, N is the number of process streams N 1 ,plus, there is a rule that is, the Minimum number of Heat Exchanger. Let us say, that is, U min that is equal to N minus 1. N is the number of,a process streams how do we get how do we get N that is number of process streams N 1 and number of utility stream N 2.

So, if there are, N number of processing streams including both hot stream and cold stream and N 2 number of utilities. So, N is equal to N 1 plus N 2 and then minimum number of Heat Exchanger we have got from here, all right. So, this is just, by commonsense you will get this. Then we are going to Pinch Technique.

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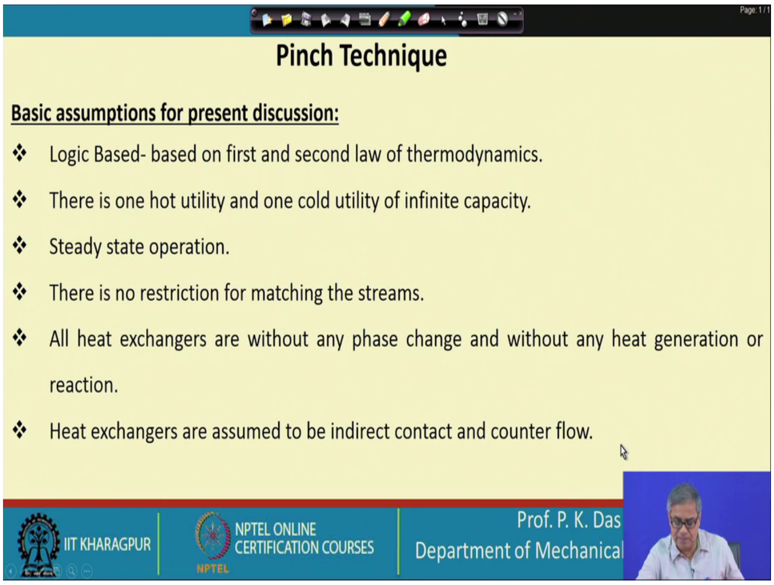

Pinch Technique the Basic assumption for the present discussion, actually Pinch Technique could be more versatile, but we are keeping it at the basic level and for that we are making some sort of assumptions that, basically Pinch Technique is logic based first and second law of thermodynamics is to be conserved conservation of first law of thermodynamics and second law of thermodynamics. So, this is universal whether for present discussion whether for another plant whether for a very a versatile implementation of Pinch Technique. So, first law and second law is to be is to be obeyed that is the basic norm.

There is only hot utility and only one cold utility of infinite capacity. So, this is specific to our discussion that there could be many hot utilities; that means, we can have, hot utilities at 100 degree Celsius, 150 degree Celsius. Let us say at 250 degree Celsius, but, and they can have different capacities.

But in the present discussion we are considering very ideal case very simple case, that we have got only one hot utility whose temperature will be more than all the, any of the rather any of the hot stream temperature and capacity will be infinite and then there is another utility that is a cold utility it is temperature will be lower than any of the cold stream temperature and capacity is infinite.

We are considering steady state operation and there is no restriction for matching two streams. In practice sometimes two streams though, they can give very good energy exchange they cannot be matched because the two streams are at two extreme end of the plant bringing them close is difficult or let us say one stream is very hazardous it is better not to put it, in heat exchanger, that particular stream along with another stream.

So, these kinds of restrictions of matching are not there. All heat exchangers are without any phase change and without any heat generation or reaction. In chemical process plant there will be many reactors which are also heat exchanger. So, that type of components we are not considering and finally, heat exchangers are assumed to be indirect contact and counter flow it is not direct contact it is counter flow indirect contact heat exchanger.

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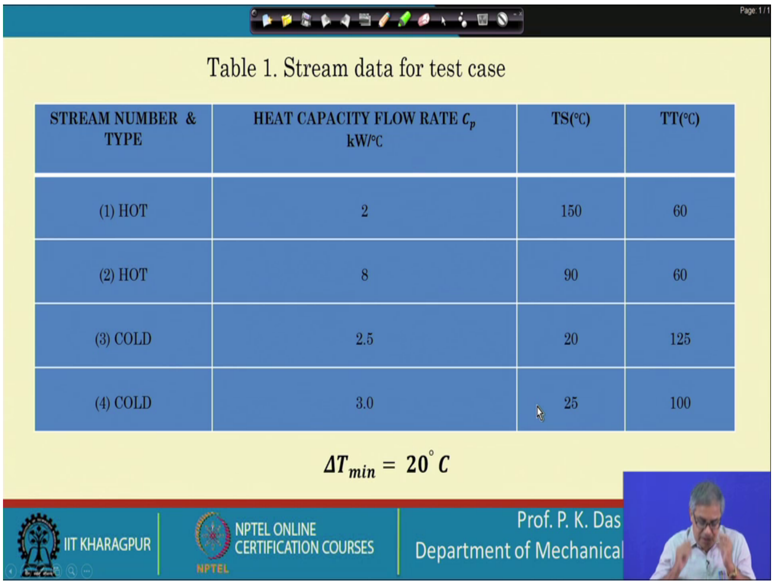
Table 1. Stream data for test case

STREAM NUMBER & TYPE	HEAT CAPACITY FLOW RATE c_p kW/°C	TS(°C)	TT(°C)
(1) HOT	2	150	60
(2) HOT	8	90	60
(3) COLD	2.5	20	125
(4) COLD	3.0	25	100

$\Delta T_{min} = 20^{\circ} C$

Now, we are trying to analyze the problem with the help of a,, we are and trying to analyze the Pinch Technique or trying to learn the Pinch technique with the help of a problem which has been taken by taken from the reference which I have given that is Linnhoff and Hindmarsh and this is a very famous problem though small.

But it is a very famous problem and many people have taken this problem for explaining, what is your Heat Exchanger Network? So, this is a small Heat Exchanger Network. We are considering there are two hot streams, and the hot streams first hot stream it is initial temperature is 150 degree Celsius, it has to be cooled to 60 degree Celsius. Second hot stream initial temperature is 90 degree Celsius, to be cooled to 60 degree Celsius.

And here, Heat Capacity Flow Rate that is., actually it should be capital C; it is m dot into C p kilowatt per degree Celsius. So, that should be the Heat Capacity Flow Rate, C p multiplied by m dot it should be multiplied by m dot. So, this is this is 2 8, 2.5 and 3 these are the different value.

And delta T minimum is 20 degree Celsius. What is delta T minimum? Delta T minimum means in a Heat Exchanger, the minimum temperature that is allowable between two fluid stream that is your delta T minimum sometimes it is also called the Pinch this is your 20 degree Celsius. We cannot design a Heat Exchanger where, the two fluids are exchanging heat and the difference of temperature between them is below 20 degree Celsius all right, Let us go to the next slide.

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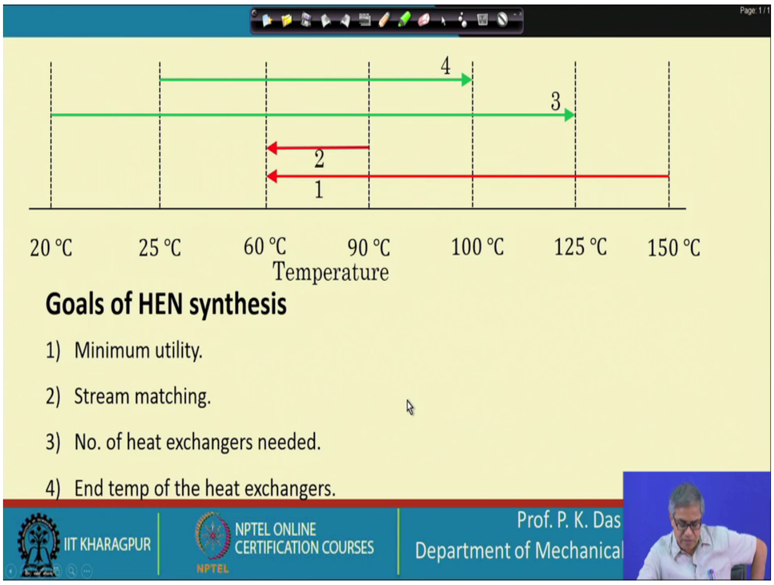

So, in this slide what we find that, this side is the hot end. So, one fluid stream we denote it by one that goes from what 150 degree Celsius to 60 degree Celsius and then, the second fluid stream that goes from 90 degree Celsius to 60 degree Celsius. Cold stream one cold stream starts at 20 degree Celsius and goes to 125 degree Celsius another cold stream starts at 25 degree Celsius and it goes to 100 degree Celsius.

So, when we have got this figure. So, what we can see, that in which temperature range heat exchange is possible. So, this tells us many things in which temperature range heat exchange is possible. We will see, really we can have heat exchange in that temperature range or not in which temperature range mutual heat exchange between two streams are possible that we can find from this figure.

So, you see suppose we consider this zone. This zone there is, there is here is the one stream from 25 degree to 60 degrees ok, but the hot stream temperature will reduce I mean will end only at 60 degree and then here again, we can see that hot stream temperature from 150 to 125 degree Celsius. No cold stream has to be brought to that high temperature. So, this is what we can see some of the temperature intervals we can see that each of the temperature either where the heat exchange I mean fluid stream initial temperature is there or the final temperature are there. So, those are strategic temperature points of the Heat Exchanger Network

So, what we can see 20 degree Celsius 25 degree Celsius, 60 degree Celsius, 90 degree Celsius, 100 degree Celsius, 125 degree Celsius at 150 degree Celsius. It becomes it becomes important in the or they become important in the Heat Exchanger Network. Another thing we can see that if we consider, the interval between 20 degree Celsius to 25 degree Celsius. Only 1 stream is there 25 to 60 degree Celsius.

There could be 2 streams 60 to 90 degree Celsius, there could be 4 streams. Then, there are 5 3 streams here 2 streams over here and 1 stream over here. So, these are part of the network the Heat Exchanger Network will be extended let us say from 20 degree Celsius to 150 degree Celsius

In this entire temperature range there are zones and in each zone there will be few number of streams. There will be some number of streams in this zone. Now, with this background let us see, what is the goal of Heat Exchanger Network synthesis? We have to have Minimum utility the way we will, synthesize the Heat Exchanger Network that we have got use of Minimum utility.

Then, that Minimum utility I have to tell that what is the minimum utility of cold? What is the minimum usage of cold utility? I can tell and what is the minimum usage of hot utility? I can prescribe. So, these two things I have to find out from the synthesis of, Heat Exchanger Network

Then Stream matching inside here you see, in this zone, 60 degree to 90 degree Celsius in this zone or in this part of the network there will be all the 4 streams now; obviously, there will be certain amount of heat exchanged between these streams, but whether there will be exchange between stream 4 and stream 2 or stream 4 and stream 1. So, that I have to tell from my Heat Exchanger Network synthesis. Then this is called stream matching and there will be different matches in different sub regions what I have shown. So, all the matches I have to tell.

Then how many heat exchangers are needed. So, that also I have to tell that if I, decide that Heat Exchanger Network if I decide upon the Heat Exchanger Network. So, not only which stream will have heat exchange with which another stream, but how many heat exchangers are to be used. Then every heat exchanger I have considered there they are indirect type counterflow heat exchangers.

So, there will be 2 streams for each stream there will be 2 temperature inlet temperature and outlet temperature. So, for a heat exchanger there will be 4 terminal temperatures, 2 inlet temperature and 2 outlet temperature. So, all these 4 temperatures also I have to tell.

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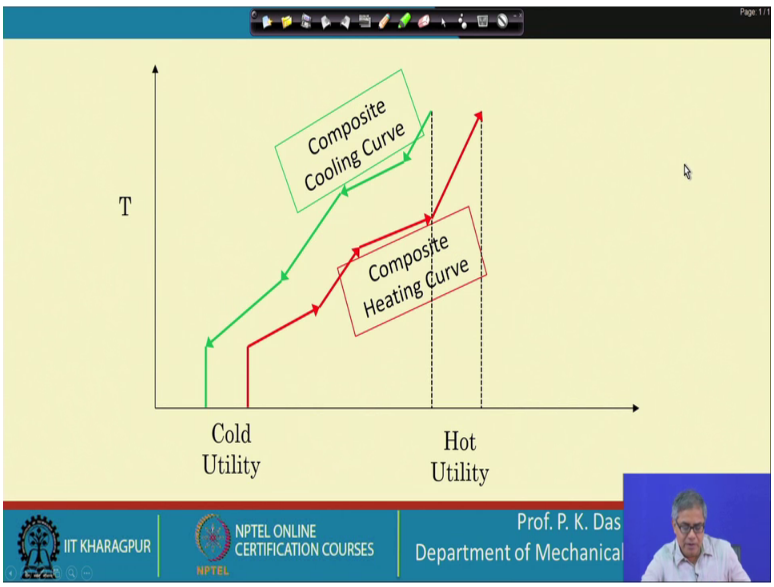

So, then I will get a complete picture of the Heat Exchanger Network., you see let me go little bit, up, here you see, that we have got or let me use this one. What we try to do then that we try to combine both I mean we try to combine all the cold streams and again we try to combine all the hot streams.

So, let say instead of these 4 sorry 4 and 3 2 hot stream we have got only 1 hot stream which we call superheated steam or composite hot stream. So, for that composite hot stream what we find that the composite hot stream will not have same heat capacity rate in the entire range. Here, it will have some heat capacity rate I have mixed both the streams. So, here the heat capacity rate will increase because 2 streams are there.

So, I can have some sort of a heat capacity rate at each and every range for the hot stream and for the cold stream. So, next what is I am doing all the hot stream I am combining together and all the cold stream I am combining together so; obviously, the heat capacity rates will be different and in different temperature range.

So, what I have done is this the, the Composite Heating Curve and Composite Cooling Curve. I have got, I could have given a different colour because, this is actually cold, but I have given red to mean that this has to be heated and this is to be cooled

So, what we see that Composite Cooling Curve this is your Composite Cooling Curve and this is your Composite Heating Curve combining all the cold streams together we got this curve and combining all the hot stream together we got this curve. So, what we can see, that there is some overlapping temperature zone.

So, there is some overlapping temperature zone and in this overlapping temperature zone there will be, heat exchange between the streams and where the hot stream will not be able to, supply the heat. So, there I have to use a, Utility and again when the cold stream will not be able to extract the heat I will have some sort of Cold Utility

So, more of it will be clear as we go I mean as we proceed further. So, out of this what we have to, remember please note this points that, based on some assumption we can solve the Heat Exchanger Network Analysis or we can have the Heat Exchanger Network Analysis.

So, what we have to have that we are basically having all the cold streams number of cold streams we are having number of hot streams heat capacity rate of each of the streams are there. So, heat capacity rate of each of the streams are there. So, we can, create some sort of Composite Curve this Composite Curve will give us in which range mutual heat exchanger is possible and in which range mutual heat exchange is not possible from there we will proceed further.

Thank you for your attention.