Plant Design and Economics
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Lecture No -46
Introduction to Pinch Technology

Welcome to module 10. Mass and energy are two commodities that are extensively used in chemical process industry. And for sustainable growth and development every industry should try to minimize the use of mass and energy. In this module we will talk about, heat exchanger network synthesis, through which we attain to minimize the use of heat energy and this is done by heat integration among the heat sources and heat sinks that are available in chemical process industries.

So, there is a technology known as pinch technology, which was developed in 1980s, in this module, will try to give you a brief introduction to pinch technology for the purpose of heat integration in chemical process industries. Please note that these days the pinch technology are also used for mass integration in chemical process industries. So, it also pinch technology also finds various applications in chemical process industry.

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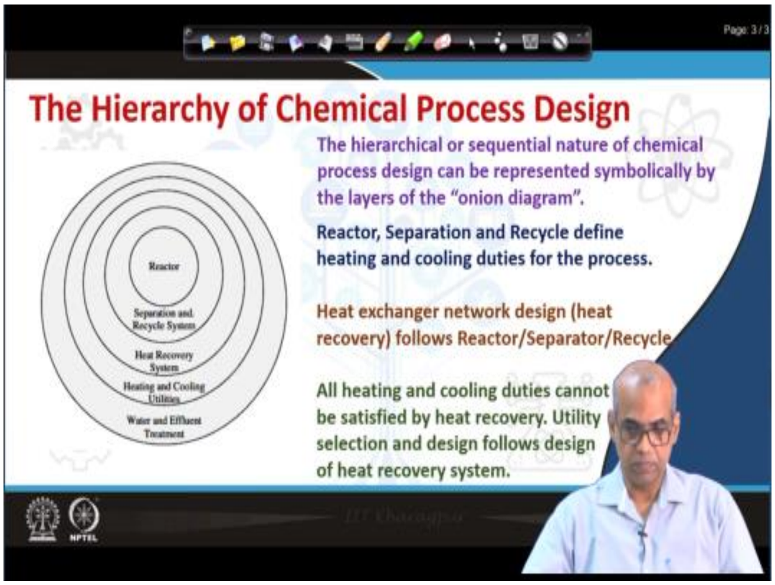

This is the only end diagram which shows the hierarchical nature of the chemical process design. Chemical reactor is often the heart of any chemical process and the design activity starts with the design of the chemical reactor. Next comes the design of separation and recycle. Once you have designed the reactor separation system and recycle, you have finalized your mass and energy balance.

So the heat recovery systems can we design after finalizing reactor separation and recycle system. So, the heat recovery system will tries to recover heat from the hot process streams that are available in industries to supply heat to the cold streams. Now all heating and cooling duties cannot be satisfied by the heat recovery from the available hot streams in your process industry. So, you definitely have to depend on additional resources of heating and cooling.

So additional resources of heating will come from use of steam and that for cooling will come for circulating water. So, after you have design it recovery system we design Utility systems. So, you select utility after the design of heat recovery system. So, this is the onion diagram which represents the general hierarchical nature of the chemical process design that we have discussed very early in this course.

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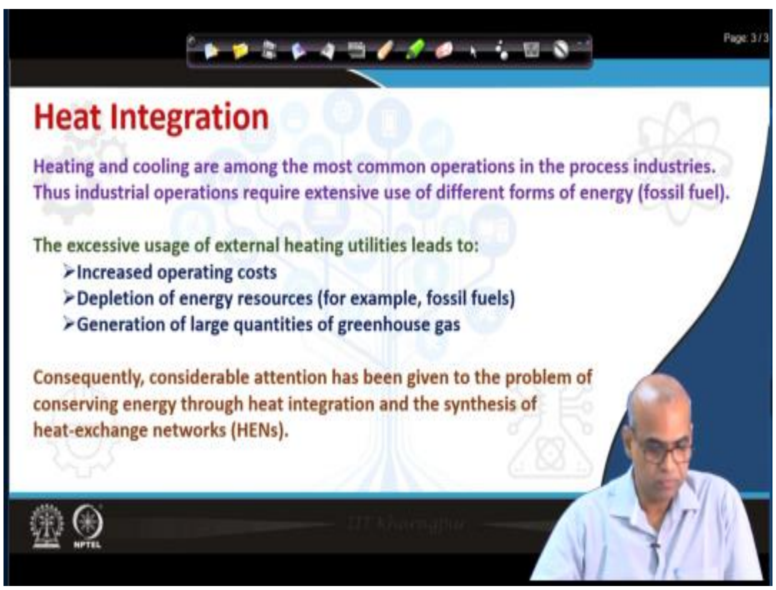

As we just discussed heating and cooling are among the most common operations in the chemical process industries. Industrial operations require extensive use of different forms of energy, such as safe fossil fuel. The excessive uses of external heating utilities will lead to certain problems. For example, your operating cost will increase. If you are using conventional energy sources such as fossil fuels;

Which are non-renewable sources; then extensive use of such external heating using fossil fuels will lead to depletion of non-renewable energy sources. Also, uses of external heating utilities leads to generation of large quantities of greenhouse gas. Therefore, considerable attention has been given to the problem of conservation energy through heat integration and the synthesis of heat exchanger network. So, every industry will try to integrate;

Process streams in order to recover energy and to the synthesis of optimum heat exchanger networks. This is required for sustainable development and growth.

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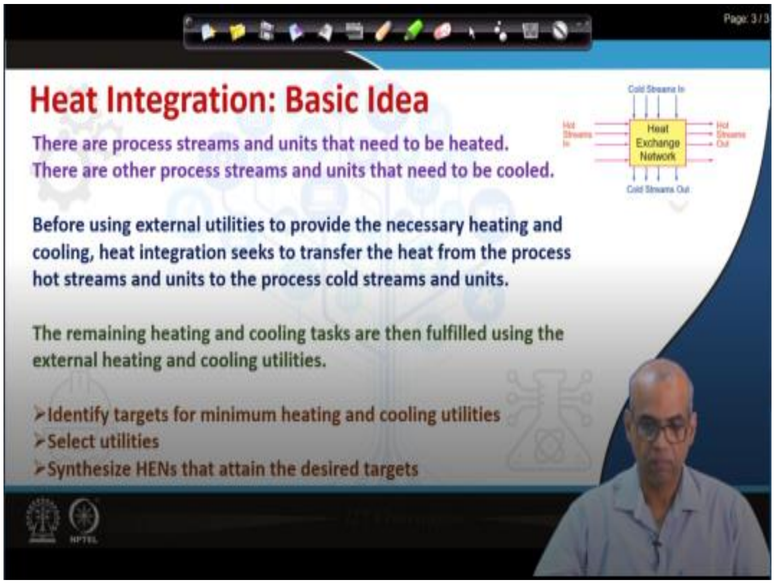

Now, what is the basic idea of heat integration? In any chemical process industry, there are process streams and units that needs to be heated. And also, there are other process streams and units which needs to be cooled down. Of course, you can make use of stream utility to heat up those process streams which needs to be heated. And for the cooling you may need cooling utility. But that will invite more cost.

So, why not first thing before we use external utilities? Is it possible to do heat integration and transfer heat from the hot process streams or units to the cold process streams and units? So, heat integration, basically seeks transfer of heat from the process hot stream and units to the process cold stream and units. And we do this of course before using the external utilities for providing necessary heating and cooling.

But, the exchanges of heat between hot process stream and cold process stream may not be enough to raise the temperature of the cold stream to the required level and also to decrease the hot streams temperature to it is target temperature. So, the remaining hot heating and cooling does must be fulfilled by using the external heating and cooling utilities. But by doing integration you will minimize the uses of external heating and cooling utilities.

Thereby it will add to process economics and of course, it will be an environment friendly approach which you lead to sustainable development and growth. So, the task of indication basically wants us to identify targets for minimum heating targets for minimum cooling utilities, selection of utilities and synthesizing heat exchanger network that will attain the desired targets. So, first we identify targets for minimum heating targets for minimum cooling utilities.

You select appropriate utilities and synthesize heat exchanger networks that will attain our desire targets.

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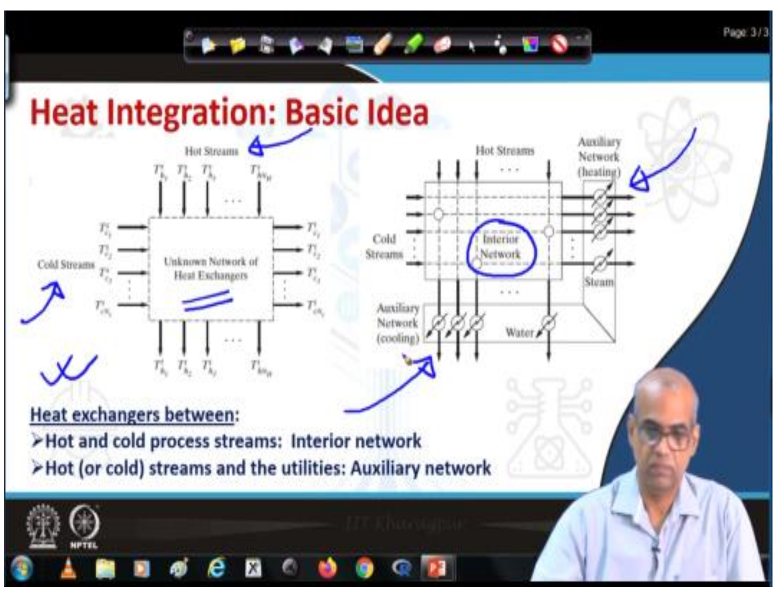

The figures that you shown, shows that in any chemical process industry there may be series of hot process streams and there may also be several cold streams. So, network of heat exchangers can be established to exchange or recover heat from the hot streams and use that to heat up the cold streams. So, you can call this as interior network. So, heat exchange between the hot stream and the cold process streams we call interior network.

Now this interior network may not be enough. Enough in the sense that when you want to raise the temperature of cold stream from the given temperature to a set temperature may be the heat content in the hot streams may not be enough to raise that temperature. So, you have to depend on external heating source. The same thing may be true for the decrease in the temperature of hot stream as well. So again, you will be depending on the cooling utility.

So, in addition to interior network we should also have network for heating network for cooling. So, we will have interior network which exchanges head between hot process stream and cold process stream and then auxiliary network for heating as well as auxiliary network for cooling which will perform the remaining heat duties after you have exchange heat between the whole heat process stream and the cold process stream and recovered the heat.

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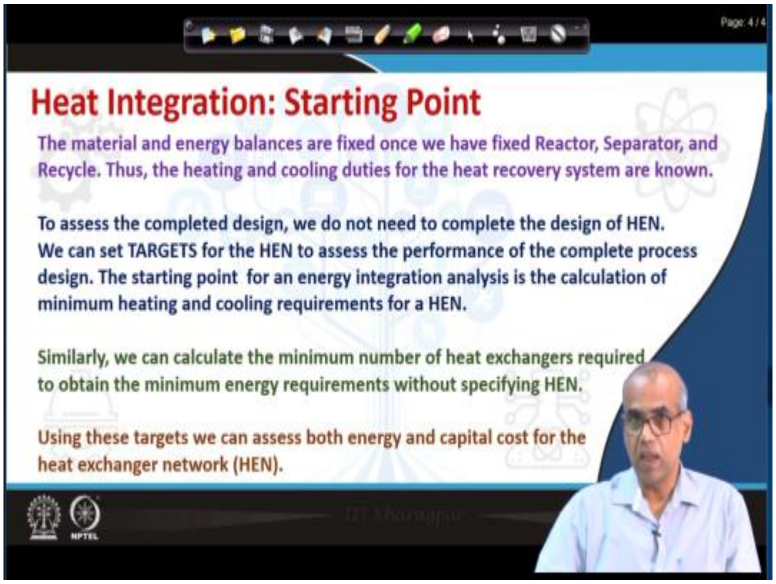

So, where do you start when you do heat integration? As we discussed before the material and energy balances are fixed for a process. Once we have fixed the reactor, the separator and the recycled system. So, during your conceptual synthesis of the flow sheet, once you have fixed the reactor system, the separator and the recycle system you are finalized your material balance and energy balance.

So, at this stage the heating duties as well as the cooling duties for the heat recovery systems are known. So, we can design the heat recovery system. Now to assess the complete design, we actually do not have to complete the design of heat exchanger network. Instead, we can set targets for the heat exchanger network to assess the performance of the complete process design. So, the starting point for an energy integration analysis is the calculation of these targets.

What are these targets? These targets are the minimum requirement and minimum cooling requirement for a heat exchanger network. Similarly, we can also calculate the minimum number of heat exchangers required to obtain the minimum energy requirement without actually fixing the specification of heat exchanger network. So, the way, we can simply set targets for the heat exchanger network to assess the performance of the complete process design.

We actually do not have to complete the design of the heat exchanger network. The information that is required to assess the performance of the complete design is the targets energy targets for the heat exchanger network. These are the minimum heating requirement and the minimum cooling requirement for a heat exchanger network. Same way we can calculate the minimum number of heat exchanger required to obtain the minimum energy requirements without specifying the heat exchanger network.

Additionally, we can also say the minimum area requirement for the heat exchanger as targets. So, using these targets we can actually assess both the energy and capital cost for the heat exchanger network. So, the setting these targets will be the starting point for analysis of any heat integration process.

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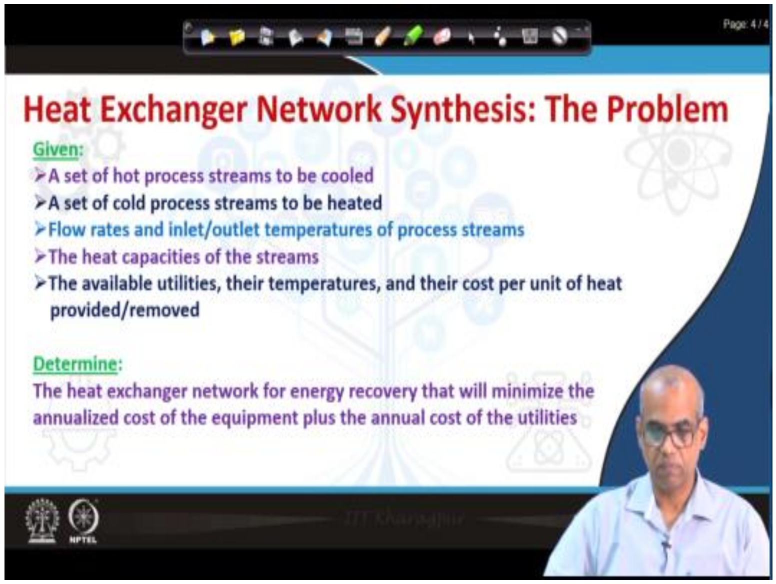

So now let us define formally the problem for heat exchanger network synthesis. We say that given a set of hot process streams to be cooled. A set of cold process streams to be heated. Flow rates and inlet outlet temperatures or process streams, the heat capacities of the streams the availability utilities, they are temperatures and their cost per unit of heat provided or per unit of heat removed.

Once these are given, we used to determine the heat exchanger network for energy recovery that will minimize the annualized cost of the equipment plus the annual cost of the utilities. So, this is the formal definition of our heat exchanger network synthesis problem.

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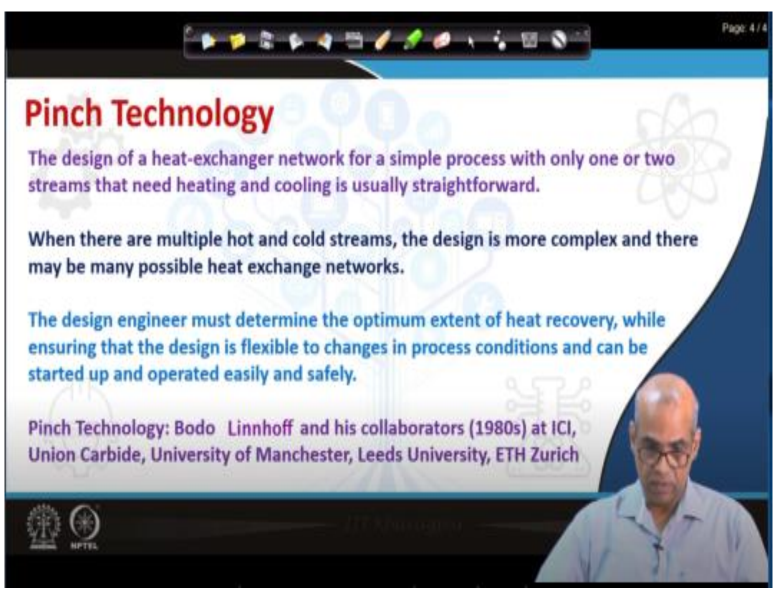

Now we will start the introduction to pinch technology as a method for heat integration. The design of a heat exchanger network for a simple process with only one or two streams that need heating or cooling is a straightforward designers. But when there are many hot streams there are many cold streams the design is much more complex and there may be many possible heat exchanger networks. So, you have to choose the optimum one or the most suitable one for your process.

The design engineer must determine the optimum extent of heat recovery while ensuring that the design is flexible enough to accommodate small changes in the process that generally takes place in industry and can be started up and operated easily and safely. So, the design heat exchanger network should recover the optimum extent of heat energy, it will ensure that the design is flexible to changes in process conditions.

And the network can be started up and operated easily and of course safely. Pinch technology was developed in 80s by Bodo Linnhoff and his collaborators at industry such as ICI Imperial chemical industries, Union carbide and also at universities such as University of Manchester, Leeds universities and ETH Zurich. Over the years, it has matured and now has been applied to various case studies and in various application such as heat indication mass indication etcetera.

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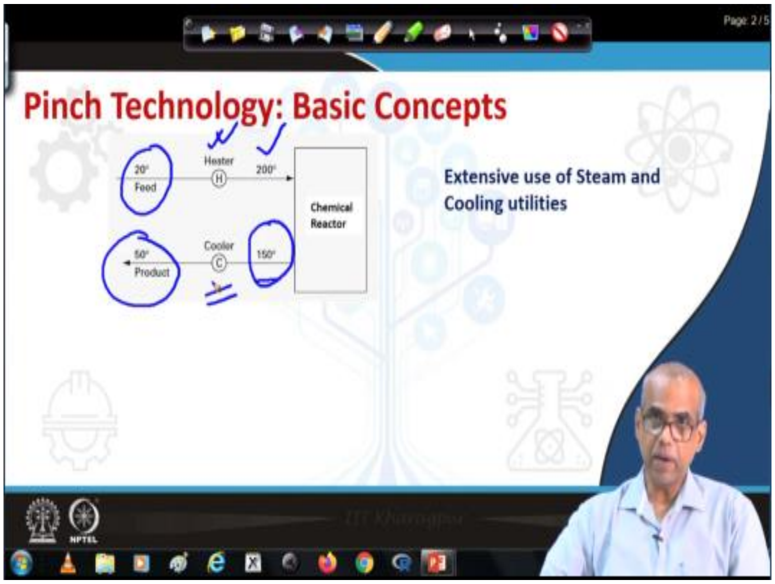

Now, let us look at this schematic. We have a chemical reactor of heat stream, which is available at 20 degree Celsius is entering the chemical reactor. And the product stream comes out from the reactor at 150 degree Celsius. The feed stream must be heated up to 200 degree Celsius before it enters the reactor and you we can use heater for that that means steam utility. Similarly, the product steam which is coming out 150 degrees Celsius must be cool down to 50 degrees Celsius and you will require cooler or cooling water utility for that.

So, if you have dependent on external utilities will be using extensively steam and cooling utilities.

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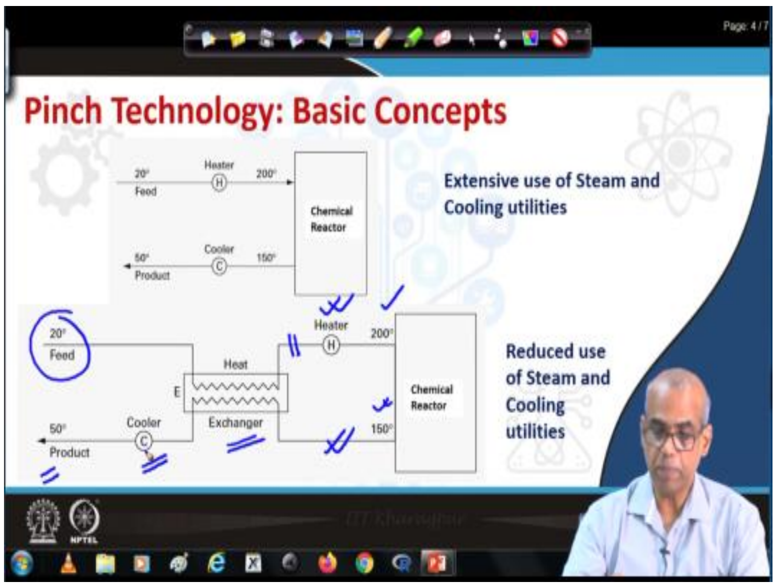

So, can you do some heat integration and say on steam and cooling utilities. We can do that by exchanging some amount of heat between the hot product steam and the cold fit stream so such kind of arrangement can be made. And of course, the additional heating will be provided by the heater and additional cooling after the exchange between the process these two process steams will be done by the cooler. So, this will lead to reduce the use of steam and the cooling utility.

In this case note that the feed stream which is available at 20 degree Celsius is receiving heat from the hot process steam that comes out from the chemical reactor. After the heat exchanger the temperature at this stage for the feed stream may not be 200 degrees Celsius. So that is why we need additional resource from the heater. The same is true for the cold stream after the heat exchange with the cold feed stream the temperature of the product stream will not drop from 150 degrees Celsius to 50 degrees Celsius.

So, you may require additional cooling utility, but of course compared to this case we have reduced the consumption of steam and cooling utilities.

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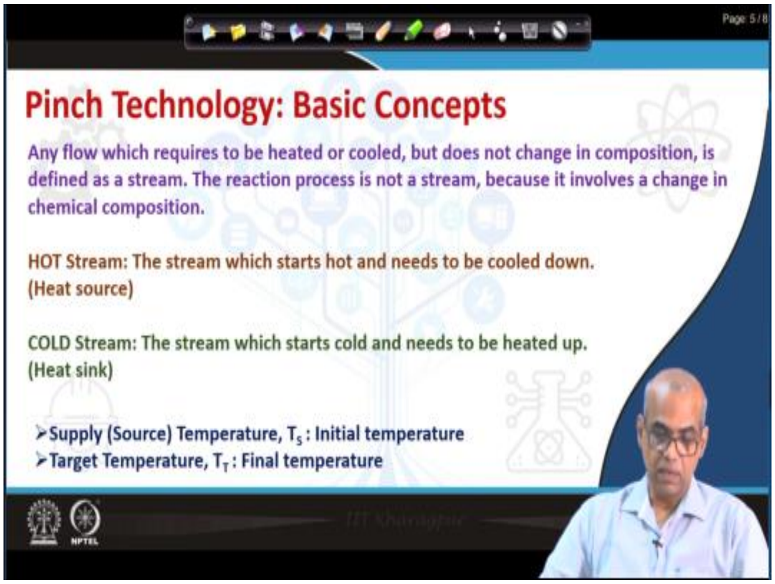

Now, let us define certain terms any flow which requires to be heated or cooled but does not change in composition is define as a stream. So, stream is any flow which requires to be heated up or cool down. But it does not change in composition. So, in the previous example, the chemical reactor is not a stream because there is a change in composition within the reactor. But the feed stream and the products in their streams that is why we are talking about feed stream coke and the product stream.

Now by definition the hot stream is the stream which needs to be cooled down. So hot stream starts hot and then cooled down. We also call it heat source. By definition the cold stream is the stream which needs to be heated up. So cold stream starts cold and then is heated up. We call it heat sink. Now every stream has then some initial temperature and final temperature. So, we define two additional terms supply or source temperature and target temperature.

Supply or source temperature is the initial temperature of the stream and target temperature is the final temperature of the stream. So, both cold stream and the hot stream has supplied temperature and target temperature. Supply temperature is the initial temperature and target temperature is the final temperature.

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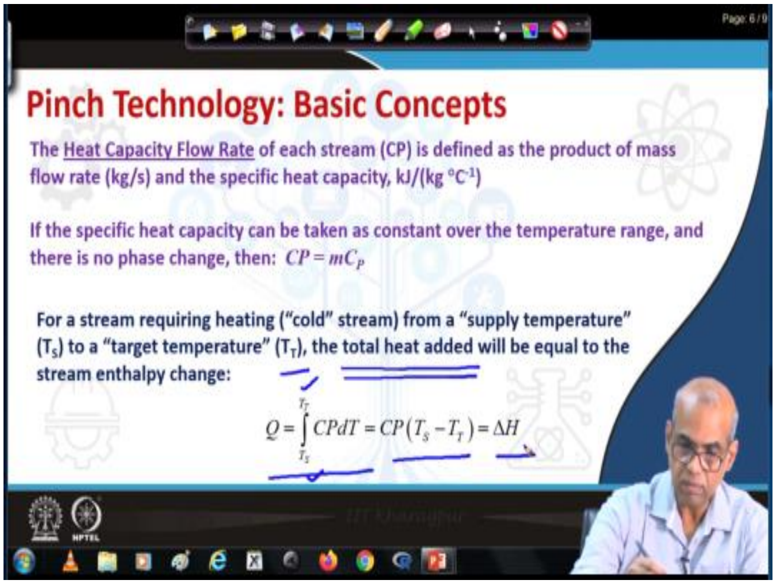

We will define one more term known as heat capacity flow rate. Heat capacity flow rate of each stream is defined as the mass flow rate of that stream multiplied by the specific heat capacity of that stream. See the specific heat capacity is taken as constant say over the temperature range of supply to the final temperature. So, initial temperature between initial temperature and the final temperature if the specific heat capacity is considered constant.

Then the heat capacity flow rate will be defined as m into CP where m is mass flow rate same kg per second and C subscript P, CP is the specific heat capacity of the stream in the unit of let us say kilo joule per kg degrees Celsius or kilo joule per kg degree kelvin. We also make an assumption here that no phase change is taking place. So, the heat capacity flow rate is mass flow rate multiplied by specific heat capacity.

For a stream requiring heating that means a cold stream from a supply temperature T S to a target temperature T T. We can calculate the total amount of heat that needs to be added. And the total amount of heat that will be added when I increase the temperature from supply temperature to the target temperature will be equal to the enthalpy change of the stream. So, the total heat added to a cold stream to change the temperature from supply temperature T S to target temperature T T will be q into C P d T integration T S to T T which is C P into T S – T T. So, this is the change in enthalpy we define.

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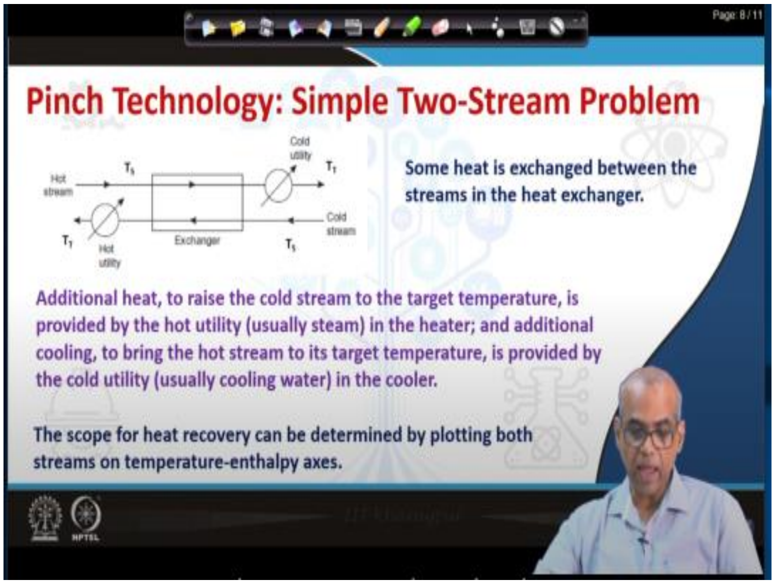

Now, let us take a simple example with only two streams. So, what you see in the figure is there is a hot stream there is a cold stream some amount of heat exchange is taking place between these two streams and also there is additional heat to raise the cold stream to target temperature. And additional cooling to bring the hot stream to it is target temperature. So, there is a hot stream and there is a cold stream they are exchanging heat here in the heat exchanger.

Then the additional requirements are supplied by the cold utility for the hot stream and by the hot utility for the cold stream. Now we can understand the scope of the heat recovery between this hot stream and the cold stream if we plot both the streams on temperature enthalpy axis.

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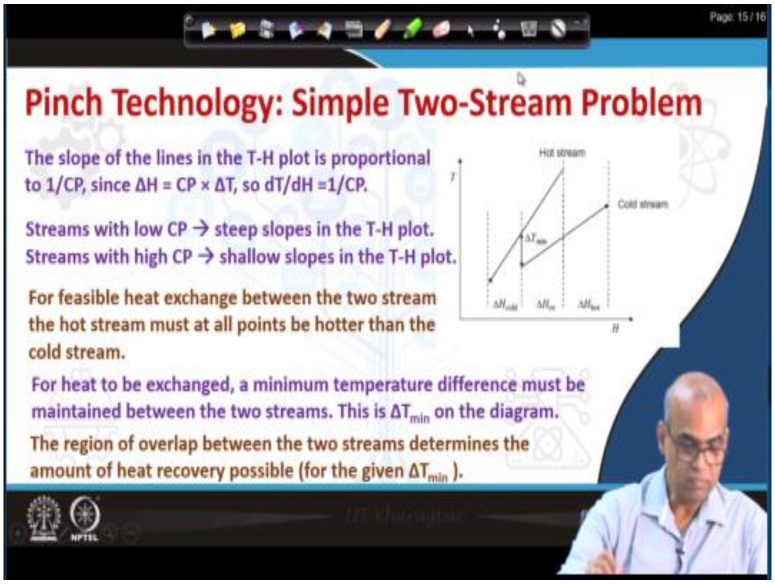

So, what you see now is the temperature enthalpy plot for both the hot stream and the cold stream. Note that it will be a straight line. We are considering that the specific heat does not change between the supply temperature and the target temperature it is a straight line. If the assumption does not hold then of course; it will be a curved line, but then we can always consider that as a piecewise linear segments. And thereby, it will be a series of straight line segments.

Now let us calculate the slope of the lines in the T H plot. We know that, delta H is CP into del T so d T d H, which is the slope of the line in the T H plot is 1 by CP. So, what it means is that the streams with low CP that means streams with low heat capacity flow rate will have very steep slope. On the other hand, steam with high CP will have low slopes in the T H plot. For feasible heat exchange between the two streams the hot stream must always be hotter than the cold stream.

Also, for heat to be exchanged, a minimum temperature difference must be maintained between the hot stream and the cold stream. So, this minimum temperature difference that must be maintained between the hot stream and cold stream is referred as delta T minimum on the diagram. The region of the overlap between this hot stream and the cold stream determine the amount of heat recovery that is possible between these two streams for the given delta T minimum.

So in this diagram, this is the hot stream and this is the cold stream. Note that this is the region of overlap between the hot stream and the cold stream. So, this region determines the amount of heat recovery that is possible. Note here, so this is the part of the cold stream which extends beyond the start of the hot stream. So, this part of the cold stream cannot be heated up.

From the heat available from the hot stream, so this energy must be supplied by the additional heat utility that means there is a steam utility. So, this is the minimum energy target or this is the minimum hot utility target. Similarly, this is the region which indicates the portion of the hot stream that extends beyond the beginning of the cold stream, so this part of the hot stream cannot be cooled down by the cold stream.

So, this must this cooling must be supplied by the auxiliary utility source that means the cooling utility that is available in the industry. So, this sets the minimum cooling utility target, so this sets the minimum hot utility target, this sets minimum cold utility target and this region of overlap tells you the energy that is recovered. And note that this is for the given delta T minimum. Delta T minimum can be varied will come to that.

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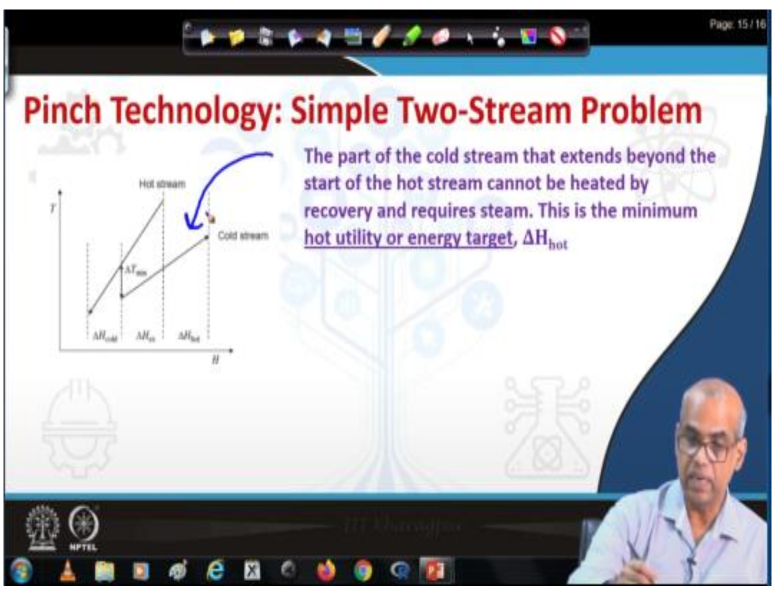

So, this is we just discussed the part of the cold stream that extends beyond the start of the hot stream cannot be heated by the recovery and require steam. So, this is the minimum hot utility or energy target.

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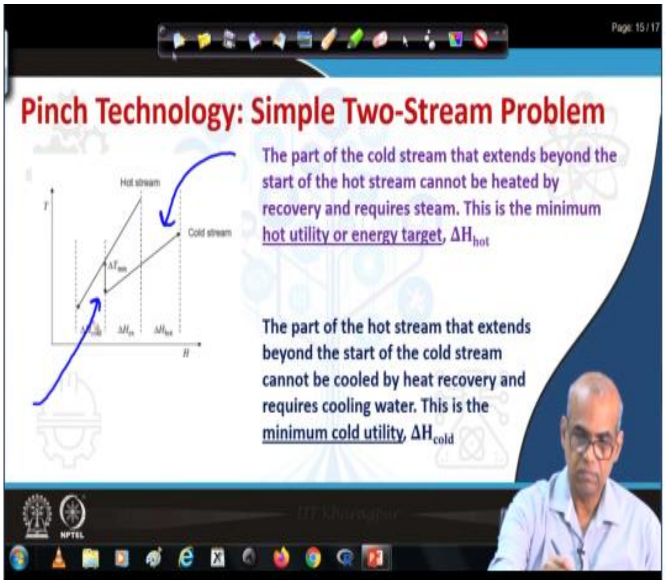

Similarly, the part of the hot stream that extends beyond the start of the cold stream cannot be cooled by the heat recovery and requires cooling water, so this is the minimum cold utility target.

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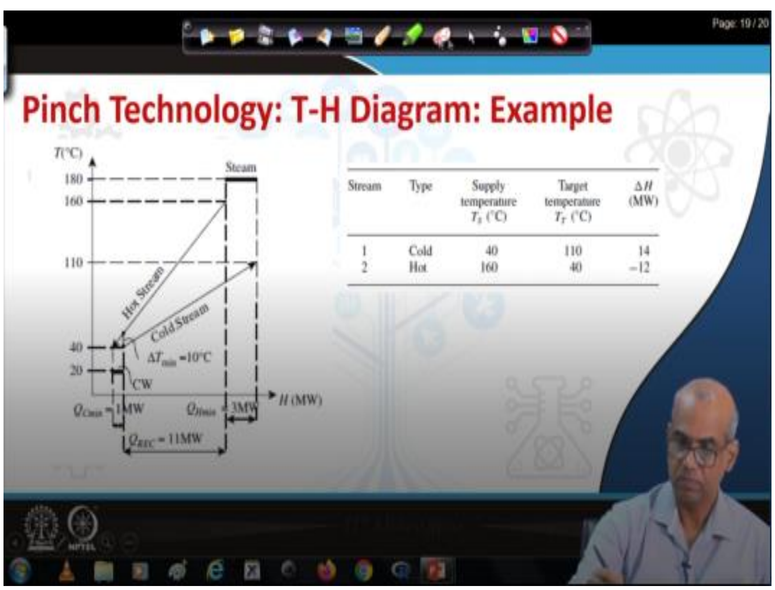

Now let us take an example with some numbers so that we can understand how much of these savings that are possible. So, you have two streams cold stream and hot stream. The cold stream starts with temperature 40. And the target temperature is 110 the hot stream is available at 160 degree Celsius and its target temperature is again 40 degrees Celsius. So, we have plotted the T H diagram for delta T minimum = 10 degree Celsius.

So here the heat recovery that is possible is obtained from this overlap region between these two streams and this is 11 megawatt. The steam utility that is required the minimum target is 3 megawatt. Similarly, the minimum cold utility target is 1 megawatt.

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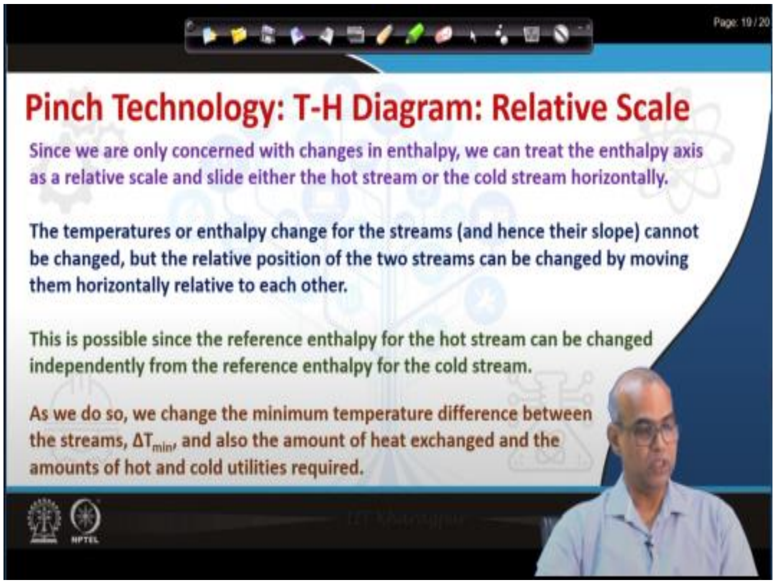

Now since we are only concerned with changes in enthalpy, we can treat the enthalpy access as the relative scale and slide either the hot stream or the cold stream horizontally. The temperatures or enthalpy change for the streams and hence their slope cannot be changed. But the relative position of the two streams can be changed by moving them horizontally relative to each other. Note that this is possible because the reference enthalpy for the hot stream can be changed independently from the reference of enthalpy of the cold stream.

The reference enthalpy for both hot stream and cold stream need not be the same we can change them independently, so it is possible for me to move horizontally these diagram. These two streams horizontally can be moved. So, they are relative positions can be changed. If we do so, we basically change the minimum difference between the minimum temperature differences that delta T minimum.

Note that, if you bring the cold stream closer to the hot stream the delta T minimum decreases, if you take it away delta T minimum increases. And by moving these streams horizontally relative to each other we not only change the delta T minimum the amounts of hot and cold utility targets will also be changed. Note here.

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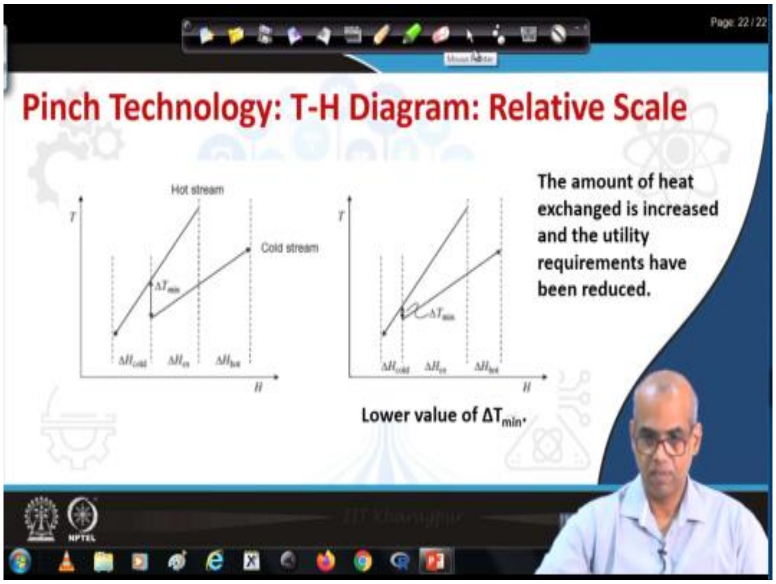

So, this was my original diagram. Now, I have decrease the delta T minimum as I decrease the delta T minimum. The region of overlap increased. So, the amount of heat exchanger recovered increased but that will then decrease the utility requirement because you are recovering more amount of energy. But of course, as you recover more amount of energy your heat exchanger area will be more and delta T minimum is decreasing.

So, the Logman temperature difference or the temperature diving force will also decrease. So that is lead to increase in capital cost because it will lead to increase the area of a transfer.

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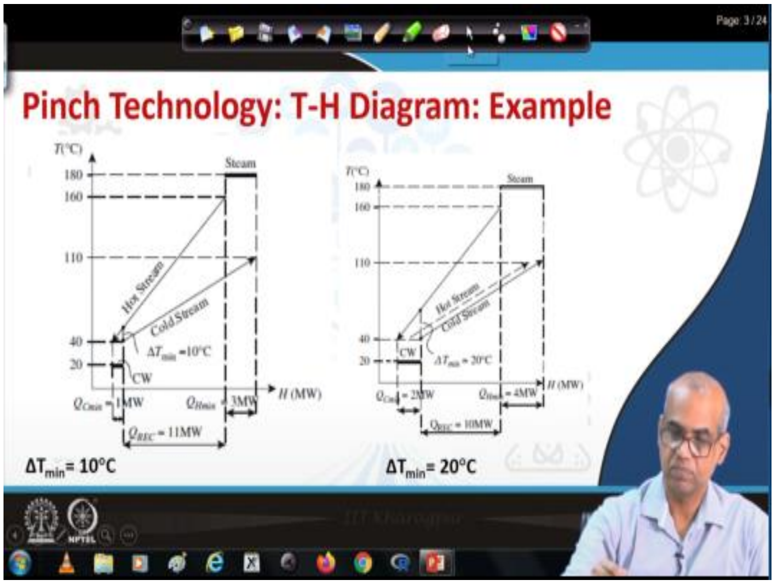

So, this is the same previous example with numbers on the process streams. So, this is my original figure with delta T minimum 10 degree Celsius. Now, let us say, I have taken the cold stream away from the hot stream. So, the delta T minimum has now decreased 20 degrees Celsius. So, note that, now the overlap between the hot stream and cold stream will decrease. So, the heat recovery has decreased from 11 megawatt to 10 megawatt.

And also, consequently the target hot utility and the cold utility has increased because we are recovering now less amount of energy.

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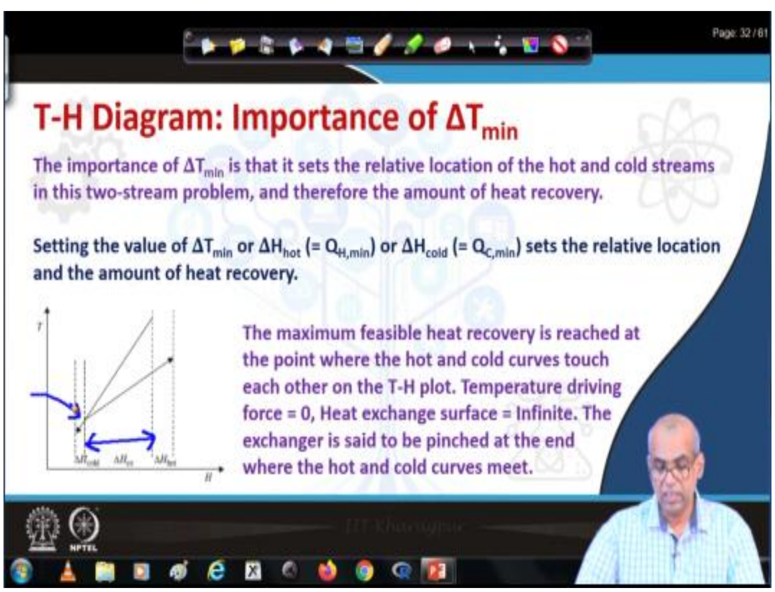

When you set the delta T minimum, it sets the relative position of the hot stream and the cold stream on the T H diagram. And it automatically sets the amount of heat that can be recovered the hot utility target as well as the cold utility target. You will see from the graph that by setting delta T minimum or by setting hot utility target or by setting the cold utility target. The relative position of these two curves on the T H diagram will be fixed.

Which; will also fix the amount of heat that can be recovered between these two process streams. Now what is the maximum amount of heat that can be recovered? The maximum amount of heat that can be recovered will be indicated on the T H diagram when there is maximum amount of overlap between the hot stream and the cold stream on the T H diagram. So, this will be obtained here when the hot and the cold curve will touch each other on the T H diagram.

Note that, this is the scenario when you will have the maximum degree of overlap between the cold stream and the hot stream. But at this stage the temperature driving force the delta T minimum has become 0. So, although you are recovering maximum amount of heat. The temperature driving force is zero. Note that you will require a heat exchanger through which this hot stream and cold stream will be passed to recover the heat.

For example, you may pass it through a shell and to heat exchanger but if delta T minimum if the temperature driving force is 0 it basically means that your heat exchange surface requirement will be infinite. We say that the heat exchanger is pinched at the end where hot and the cold curves meet.

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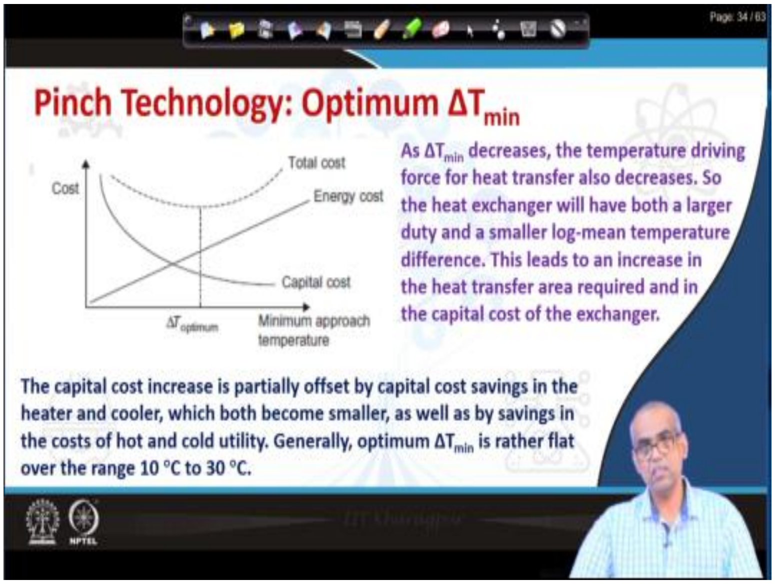

So, delta T minimum must be set back with practical consideration. As the delta T minimum value decreases, there is greater degree overlap between the hot stream and cold stream energy recovery increases. So, you save money on the utility cost operating cost decreases. But to recover more amount of energy, you need heat exchanger with more surface area. Also, the temperature driving force for the heat transfer decreases with decreasing value of delta T minimum.

So, heat exchanger will have both larger heat duty as well as smaller temperature driving force LMTD value. So, decreasing the delta T minimum value will lead to increase in heat transfer area which will lead to increase value of capital cost of the exchanger. But we are saving on the utility cost. Also, you have we will require lower size heater and cooler. But with decreasing value of delta T minimum and in the limiting value of delta T minimum 0 heat transfer area becomes infinite.

So, the cost will also be infinite. So, the capital cost will increase with the decreasing value of delta T minimum. But energy cost will decrease. So, with the decreasing value of delta T minimum capital cost will increase but energy cost will decrease. Exactly reverse will happen when delta T minimum increases. When delta T minimum increases there is less amount of overlap heat exchangers surface area will be reduced capital cost will decrease.

But now utility cost will increase to energy cost increase. So, If I combine both the energy cost of the capital cost I will get the total cost. So, the variation of the total cost with respect to delta minimum will now show a minimum. That will give me economic delta T optimum. So, economic delta T minimum value most economic delta T minimum value will be obtained from cost consideration. Both capital cost and the operating cost.

This delta T optimum is generally flat over a broad range of temperature from 10 degrees Celsius to 30 degree Celsius. So, between 10 degree Celsius to 30 degree Celsius this delta T optimum is not very sensitive. We will talk about delta T minimum more in our future classes. With this we stop our discussion here.