Energy Conservation and Waste Heat Recovery
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Lecture – 34
Heat Exchanger Network (HEN)

Hello, everyone welcome back for energy conservation and waste heat recovery. If you recall, we were discussing regarding run around coil, which is a special kind of heat exchanger for waste heat recovery. It is also called freed coupled heat exchanger. We were doing some analysis, simplified analysis to determine; what is the rate of heat transfer in a run around coil.

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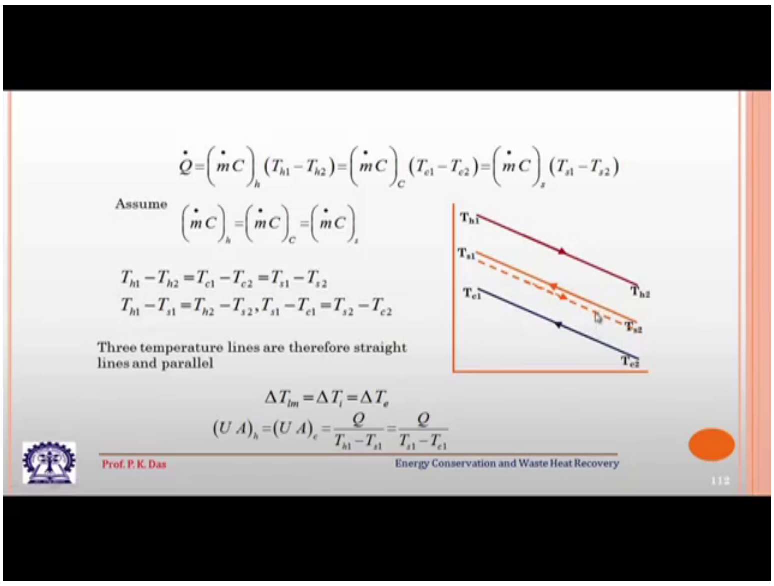

So, if we again pay our attention to this particular slide. So, here, we have made a drastic assumption, this may not be true in actual case that m dot C h that is the heat capacity rate of the hot fluid that is equal to m dot C c, heat capacity rate of the cold fluid that is equal to m dot C s heat capacity rate of the secondary fluid, which couples the hot end heat exchanger and the cold end heat exchanger. So, like this.

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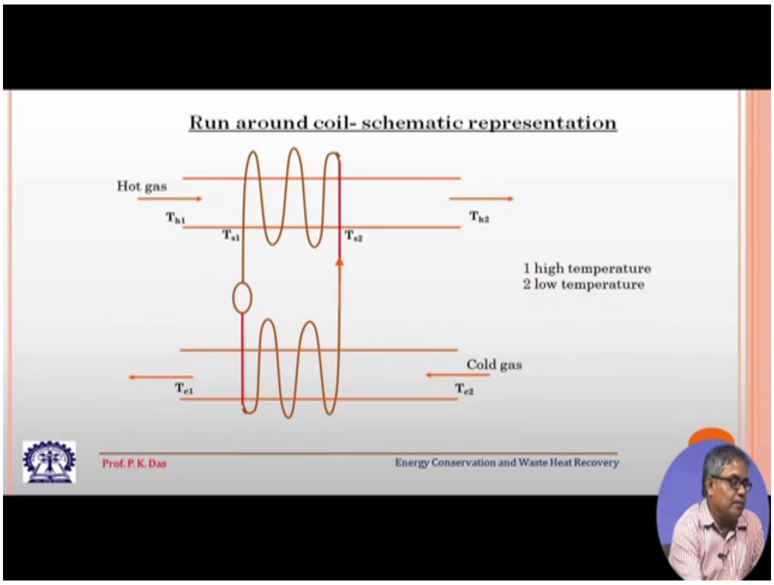

So, this is your hot end heat exchanger and cold end heat exchanger, there is a common fluid, for this 2 heat exchanger, which is passing through a loop with the help of a pump .

So, if this 2 fluid in the heat capacity rate of the three fluid streams are equal, then what we get, if we are considering through you are considering counter, current flow arrangement, then for the hot end heat exchanger, we get this kind of temperature change along the length of the heat exchanger and for the cold end heat exchanger, we get this kind of change of temperature, along the length of the heat exchanger.

Temperature change with the length of the heat exchanger that is linear and the temperature difference inside a heat exchanger, throughout the length that is constant temperature difference between 2 feet or local temperature difference between the fluid stream, that is constant along the length of the heat exchanger. So, with this we know that if this kind of temperature difference is there, then we need not calculate LMTD or any kind of mean temperature difference, because everywhere the temperature, local temperature, difference is the same and if T h 1 minus T s 1 is called delta T. So, delta T is along the entire length of the heat exchanger starting from the one end of the heat exchanger to the other end.

So, three temperature lines are therefore, straight lines and parallel delta T L m which could be called as L M T D or mean temperature difference that is equal to delta T i the temperature difference between the 2 fluids at the inlet, that is equal to delta Te that is the temperature difference between 2 fluid at the exit.

U A if we consider the hot side heat exchanger U A h is equal to U A c this also comes from this drastic assumption we have made that m dot C h is equal to m dot C c and that is equal to m dot C s that is the U A product of U A for each of the heat exchanger either hot side or cold side that is equal and that can be given by Q by the temperature difference delta T of the hot heat exchanger or Q by delta T the temperature difference of the cold end heat exchanger.

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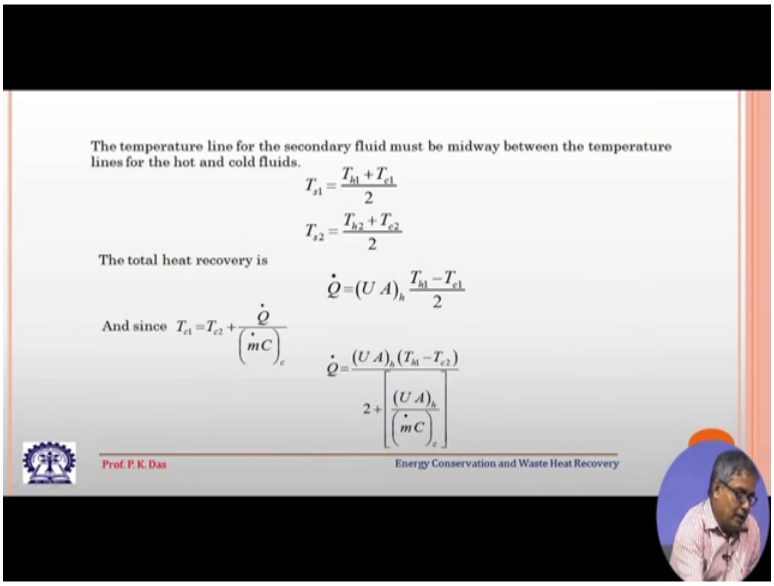

So, again you see let us go back; what is happening to the intermediate fluid stream or secondary fluid stream that is important for the analysis of the heat exchanger without considering that we cannot do the analysis, but at the end of the day we are not bothered about what changes are happening, what temperature changes are happening to the secondary fluid stream. We are bothered about how much heat is transferred or at the next place, we are concerned, what is the temperature outlet? Temperature of the hot fluid stream, what is the outlet temperature of the cold fluid stream; assuming that in most of the application, the inlet temperature of the hot fluid stream and the inlet temperature of the cold fluid stream, these 2 are known quantities and of course, the heat exchanger characteristics like U A that is a noncore known quantity and the heat capacity rate, those are known quantities, known parameters.

So, if that is our goal that you want to calculate the heat transfer rate, then you see the hot side inlet, temperature is known cold side inlet, temperature is known, let us assume the hot side outlet, temperature to be T h 2 cold side outlet temperature to be T c 1. So, what one can get, the difference between these 2 end is T h 1 minus T s 1 for a particular heat exchanger. We will be interested in this difference Th 1 minus Ts 1 or Ts 1 minus T c T c 1 and in this special case, where we have made lot of simplified assumptions. So, T s 1 will be in between T h 1 and T c 1 in between means midway between.

So, one can tell that T h 1 minus T s 1 is equal to T s 1 minus T c 1. Similarly, T h 2 minus T s 2 is equal to T s 2 minus T c 2 this follows. So, that is what, we have written that T s 1 is equal to T h 1 plus Tc 1 by 2 and T s 2 is equal to T h 2 minus T c 2 by 2 . So, total heat recovery is Q dot that is equal to that is T h 1 minus T c 1 by 2 mind, that this is the inlet temperature of the hot fluid, but this is the outlet temperature of the cold fluid and in most of the cases, we do not know the outlet temperature of the cold fluid. This divided by 2, because delta t in the hot heat exchanger will be half of this quantity and again, I like to remind, these are at 1 end of the heat exchanger and one of the heat exchanger and for the cold fluid stream. We can write down this energy balance equation. So, now, T c 1 that should be replaced by this particular formula bringing in T c 2 which is known.

So, some sort of algebraic manipulation, you can prove that Q dot is equal to this quantity, where U A h that is the product of overall heat transfer coefficient and heat transfer area for the heat hot end heat exchanger, it is known T h minus T c 2 inlet temperature of the hot fluid, inlet temperature of the cold fluid, this is also known in most of the practical application and then again UA h known quantity m dot C at the cold side; that means, heat capacity rate of the cold side, that is known quantity.

So, by this we will be able to find out the heat transfer rate; obviously, the analysis is much simplified, some drastic assumptions we have made for this analysis, but even then it will give us quite a few good information.

First thing is that, it will depend on the 2 inlet temperatures; that means, rate of heat transfer will be dependent on 2 inlet temperatures, inlet temperature of the hot fluid and inlet temperature of the cold fluid. It will depend on the product of U A h or U s c and again. So, it will increase with this, but U A h has got some sort of a some sort of a what should I say, conflicting effect on it one way, it is increasing and one way it is also decreasing the rate of heat transfer, these 2 effects are there and; obviously, m dot C, this will increase the rate of heat transfer. If you see this has got a tendency to increase, the rate of heat transfer. So, this gives us some idea that which parameter has got, what effect on the rate of heat transfer. This is a, this analysis can be made more realistic, but then the analysis will be complex. So, I avoid that, I like to mention the application of run around coil.

Run around coils are very extensively used for air conditioning application, if we go back, the go back to the figure which, I have shown at the beginning.

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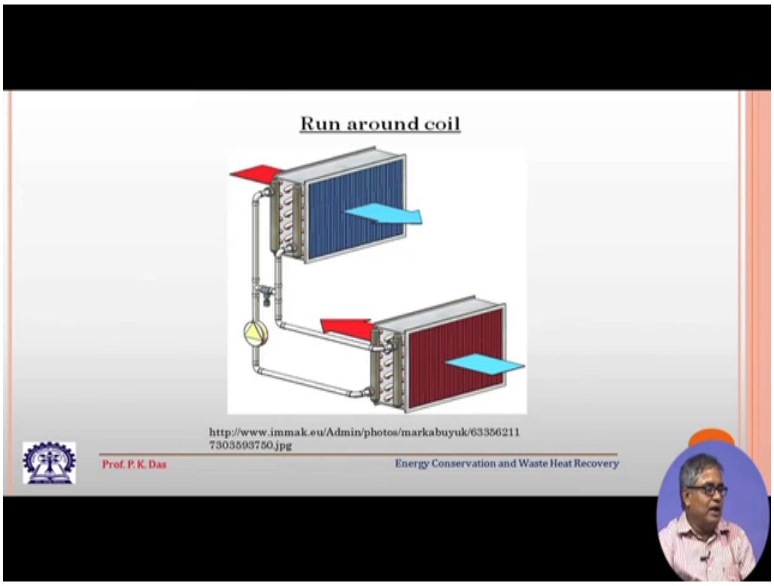

So, this could be the air which is coming out of a room. Let us say, we have got an application of some winter situation in a cold country and room heating is there, but the room air is to be expelled from the room to the atmosphere, while the room air is coming. It is having certain amount of thermal energy, that can be extracted by a fluid stream and from outside we are taking fresh cold air that has to be heated, but before heating, using some sort of electrical heater or some sort of a bartner, if we can utilize some of the heat given by the exhaust hot stream of air, with this run around coil type of heat exchanger, then we can shape certain amount of energy.

So, this is one example of run around coil. This is one of the main application of run around coil, but there could be other applications also big industrial system. There could be other application also, but in most of the cases for gas to gas, heat exchange from a hot gas stream to a cold gas stream, heat exchange this kind of run around coils are used. It has got limitations also, if the streams are far apart then of course, there will be losses. We have neglected the losses from this coil, but there will be some amount of losses more than that there is some amount of pumping power needed. So, this pumping power is some extra input, and that is the penalty you have to pay for extracting thermal energy.

With this we, I come to an end regarding our discussion of special heat exchangers which are used for waste heat recovery. Now, I like to switch over to a topic, which is quite unique and it is related to heat exchanger, but it is not related to a typical kind of heat exchanger, it is regarding heat exchangers, when a large number of heat exchangers are used in some sort of a plant or industry or how heat can be or energy can be conjured by the use of heat exchangers not a single heat exchanger, but a number of heat exchangers.

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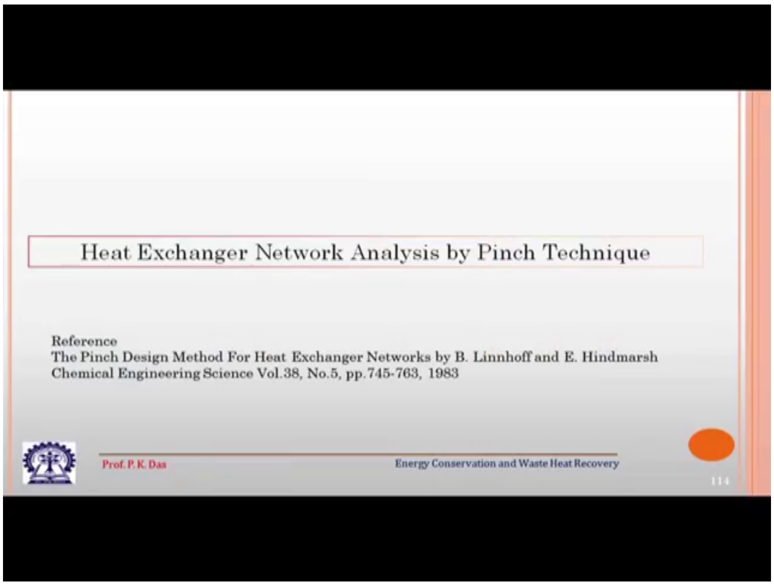

So, we will go now, to heat exchanger network analysis by pinch technique. This is has been taken, the entire thing which I will discuss here, including the example that is that has been taken from this reference. The pinch design method for heat exchanger networks by Linnhoff and Hindmarsh. It was published chemical engineer, in chemical engineering science, in 1983.

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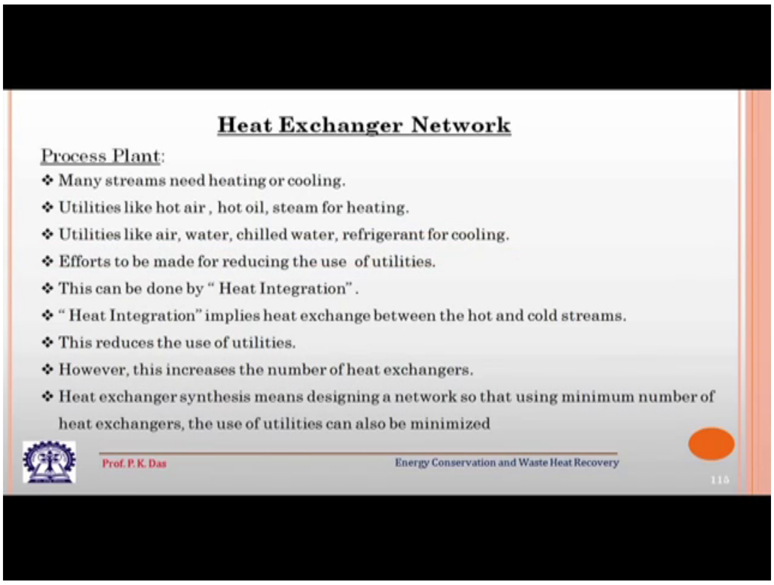

So, let me first introduce, what is a heat exchanger network. So, there are process plants or chemical plant petrochemical refineries, where there are many streams, many streams of fluids. Some may be liquid, some may be gas, some may be changing their phase and these many streams of liquids. This each stream needs either heating or cooling; that means, a particular stream will be available at a particular temperature and there is a that could be called as a supply temperature and then for this stream there is some sort of a target temperature to that temperature that stream has to be brought to.

Now, this target temperature, we can achieve either by heating or by cooling. How it can be done, generally one can use utilities for this purpose. Utilities like hot air, hot oil steam can be used for heating, this stream and utilities like air at normal temperature, ambient air, water chilled, water refrigerant, that can be used for cooling this stream or going to a low target temperature.

Now, this utilities means these are extra cost. I have to either chill a liquid stream to get chilled water or I have to use some sort of refrigerant for that a refrigeration plant is needed even if, I use ambient air for that some plan is needed. So, no utility can be obtained without paying any cost so; obviously, for a good plan design, it will be always desirable to use less amount of utilities.

Efforts to be made for reducing the use of utilities, because utilities means running cost and utilities also means capital cost, because if I had to have chilled water lot of chilled water. So, I have to along with the process plant, I have to also have some sort of a chilling plant from where I can get the perennial supply of chilled water and; obviously, the plant size will also increase.

Efforts are made for reducing, the use of utilities, this can be done by heat integration, heat integration is a very common topic; technical term which is used in chemical engineering. So, heat integration means utilization of thermal in thermal energy in a particular plant in a proper fashion

If cooling is needed, we have to see whether we can do these cooling internally without taking any cold utility. If heating is needed, we have to see, whether we can do the heating again, internally without paying some money, for the hot utility. So, this is called heat integration heat integration implies heat exchange between the hot and the cold streams this reduces the use of utilities; obviously, when we do this then a hot stream supply temperature is very large and we have to come to a low target temperature and that can be done without using any utility one stream is to be heated. So, that stream can be heated with the help of that hot stream, but this heating of a stream and cooling of another stream that cannot be done just automatically we have to have some equipment for that and that equipment is called heat exchanger.

So, when we try to do this internal heating and cooling then we have to use heat exchanger. So, when there is heat integration, then we have to use number of heat exchangers; however, this increases the number of heat exchangers.

The heat exchanger synthesis means designing a network. So, that we use minimum number of heat exchanger and use the minimum amount of utility. So, both this thing we have to take care of. So, it is like this, if we reduce the utility use of utility. We reduce the running cost of the plant to some extent. We may reduce the initial cost of the plant, because we have not to provide some sort of a chilling plant or we have not to provide some sort of a boiler, but what we say mainly is the running cost.

But if we have to do it by heat integration, then we have to we have to have number of heat exchangers. So, we are saving the running cost, but we have got substantial amount of initial cost. So, we have to make some sort of a balance between this running cost and the capital cost or initial cost investment cost. So, that we can have ultimately a profitable plant, from where we get the product at the lowest kind of production price.

So, this is; what is the target of our heat exchanger network analysis or heat exchanger network synthesis.

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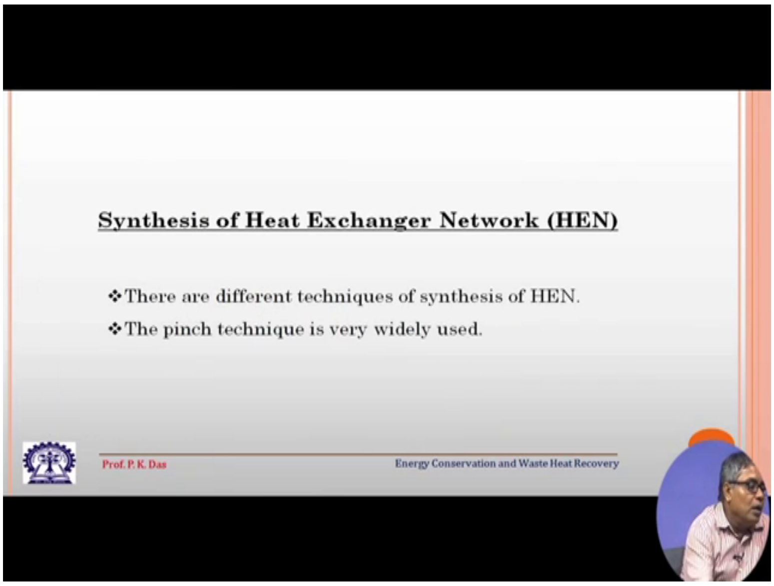

Synthesis of heat exchanger network; heat exchanger network short form is H E N Hen, that there are different techniques for synthesis of Hen and out of that the pinch technique is very widely used. There are other techniques also other programming techniques are available. Heat exchanger network could be quite complex, there could be heat exchanger network which we design at the beginning of the plant design that is relatively simple, but sometimes the heat exchanger networks are to be designed when a plant is already operating.

So, that needs retrofitting or some heat exchanger network has been designed at the beginning the plant capacity has been increased by some sort of changes intermediately. So, we have to change the heat exchanger network. So, these are complex kind of problems, we will try to see simple the principle of heat exchanger network analysis that to not by all the available methods. We try to apply the pinch technique which is a very well established well accepted and widely used technique.

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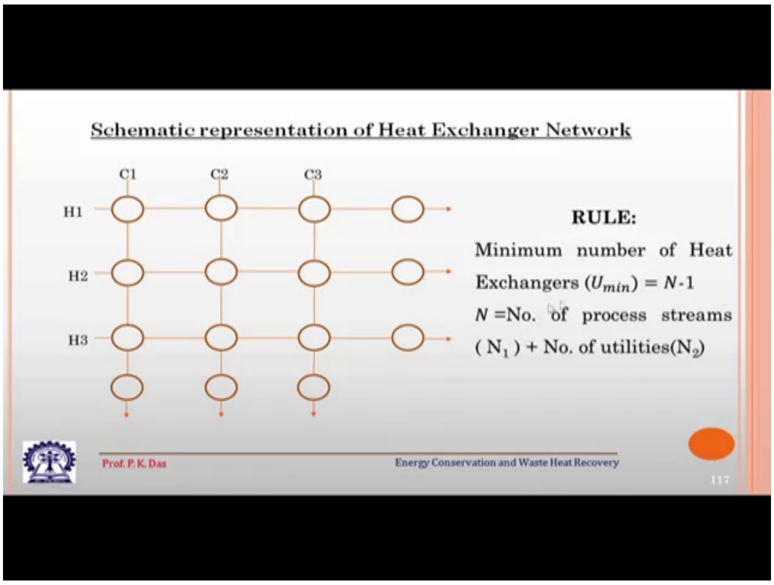

The schematic representation of heat exchanger network that that is like this; so, let us say we have got number of cold streams; that means, these streams which are having a low supply temperature and which are to be heated to some different temperatures the end and we have got number of hot streams supply temperatures are high, but they are to be cold ultimately to some low temperature not that all the supply temperatures are same for cold streams not that all the supply temperatures are same for the hot streams similarly the target temperatures are also not same for the hot streams and the cold streams.

So, how it is done c one c 2 c three they are the typical cold streams represented in this figure H 1, H 2, H 3 are the typical hot streams represented. So, for C 1, C 1 will go to the target temperature while achieving the target temperature it will have different heat exchangers in between. So, it is the temperature of this stream C 1 that is gradually being increased, but that increase may not be sufficient for achieving the target temperature for C 1. So, at the end we should have the utilization of some hot utility to bring it to the target temperature.

So, for each of the cold stream we can see there could be number of intermediate heat exchangers not that all of them will have same number of intermediate heat exchanger, but ultimately they should have or they might have some sort of a utility heat exchanger to bring their temperature to the target temperature this is true for the hot heat, hot streams also while a particular hot stream will achieve the target temperature in intermediately it will reject, it to some cold streams, but ultimately, it might need cooling by some cold utilities at the end to reach the target temperature precisely.

Now, this is a problem of combinatrodics, how we match these hot streams and cold streams. So, that minimum number of heat exchangers are there and minimum amount of utilization of the utilities are there minimum usage of utilities, are there and there is a rule that minimum number of heat exchanger, U minimum that is N minus 1 where N is the number of process, things plus number of utilities. So, from there we get the minimum number of heat exchangers.

In most of the cases, when we go for heat exchanger and network synthesis so that some amount of heat integration is possible or some amount of heat integration is achieved so; obviously, we cannot restrict to this minimum number. So, this number will increase, but this number at least gives us that what could be the minimum number and what could be our target for having the number of heat exchangers.

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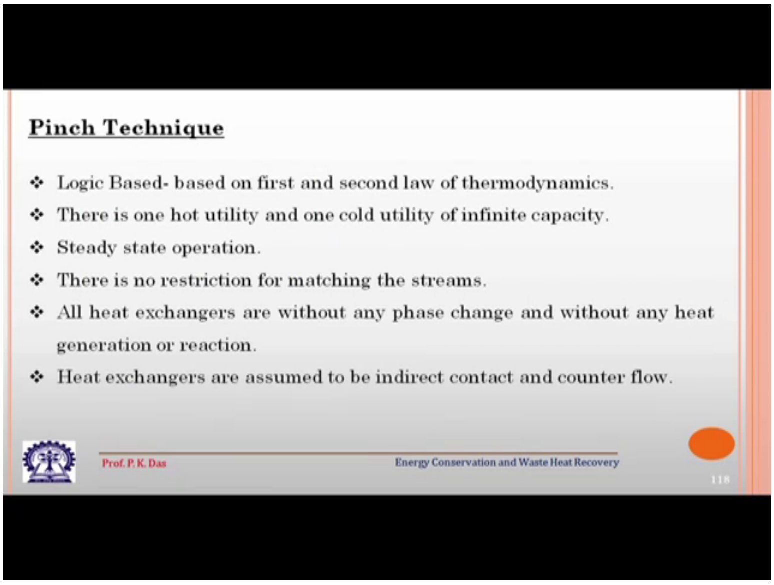

With this background, let us go to the heat exchanger synthesis, for with the application of Pinch technique, Pinch. Let me give some background, the Pinch technique is a logic based technique and this is based on the laws of thermodynamics, first law and second law of thermodynamics, we follow for the Pinch analysis in a very intelligent manner and we never violate the first law or second law of thermodynamics; obviously, if we violate this basic laws of nature, then the design will not be fruitful. So, by abiding these laws, we try to get the optimum kind of arrangement of the stream and heat integration.

For the analysis, which we will follow, we will assume that there is only one hot utility and one cold utility of infinite capacity in a practical situation in a plan. There could be number of utilities. Let us say that some cooling is done by air, ambient air and some cooling is done by chilled water. So, that could be the possibility in plant and in many cases, that is the scenario, but for our analysis to keep things simple, we assume that only, there is only one hot utility and one cold utility their capacities are sufficient. So, that they meet all the requirement of hot utility and cold utility.

Then we assume that it is steady state operation transient case. We do not consider and there is no restriction for matching, this streams in actual plant, there will be restrictions, because these streams their proximity, may not be there. Let us say there is a hot stream, which can reject it, but the cold stream, which can pick up heat that may be far apart from it. So, it is not possible to transfer or exchange heat between in the hot stream and cold stream. We have taken in example, it can be the situation can be like this, that 2 fluid streams depending on the nature of the fluid they should not be brought in close proximity within one heat exchanger, considering the safety or prevention of hazard. So, this is not permitted. So, this kind of situations could also be there.

Then all heat exchangers are without any phase change and without any heat generation or reaction. So, there could be for heat integration. We have to also consider in a chemical plant, if there is a reactor. So, from there from the reactor also one can have some sort of heat integration, but that kind of situation, we are not considering. We are considering, there are streams and the streams are in single phase. There is no phase change, all these things which I am taking as assumption they are flexible. I mean these assumptions can be relaxed in the, with the penalty of, with the cost of complexity in the analysis.

The heat exchangers are assumed to be in direct contact and counter flow; that means, the heat exchangers are of course, there could be cross flow or parallel flow heat exchanger, but we assume all of them to be counter flow and heat exchangers assumed to be in direct contact recuperator. There is no direct mixing of 2 stream, though those kind of heat exchangers are also possible and it is also possible to take care of them in a heat exchanger network, but in the present discussion, we are not doing this. So, with this background in our next lecture, we will start the synthesis of heat exchanger.

Thank you.