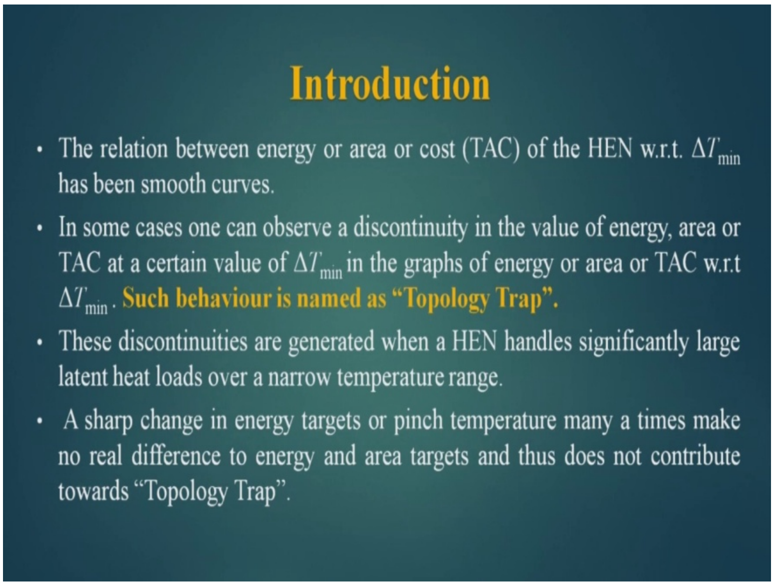
Process Integration
Prof. Bikash Mohanty
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Module - 4
Targeting
Lecture - 13
Topology Trap

Welcome to the lecture series on Process Integration. The topic of this lecture is topology traps, it has been observed while doing energy targeting that for some values of delta T minimum, the hot and cold utility requirements fluctuate sharply that is it shows some discontinuity in the utility versus delta T minimum curves. Due to this sudden up rise or fall of hot or cold utilities for certain values of delta T minimum, it creates problem in the design, because the heat exchanger network cannot be operated in those ranges of delta T minimum, because it posses uncertainty. The same thing is also visible in the determination of pinch temperature. We have seen that for certain values of delta T minimum, the pinch temperature also undergoes sharp changes or you can say that pinch versus delta T minimum graphs show discontinuity. Now how to tackle such problems and why such thing occurs, to get the answer of all these questions, let us see about the topology traps.

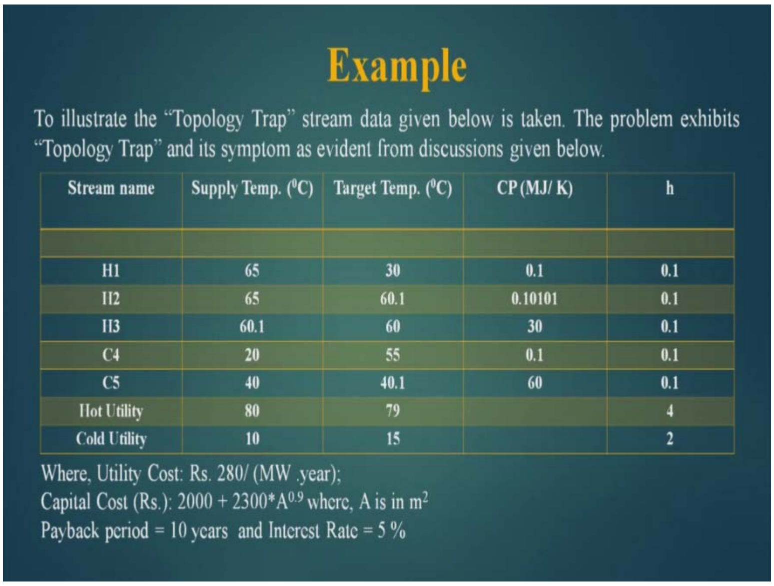
(Refer Slide Time: 02:41)



The relation between energy or area or cost of the heat exchanger network with respect to delta T minimum has been smooth curves, up till now we have seen this that energy area and cost figures or cost plots with respect to delta T minimum has been smooth. However, this is not always true. In some cases, one can observe a discontinuity in the values of area, energy or TAC at certain values of delta T minimum in the graphs of energy or area or TAC with respect to delta T minimum when we observe such discontinuities such behavior is termed as topology trap.

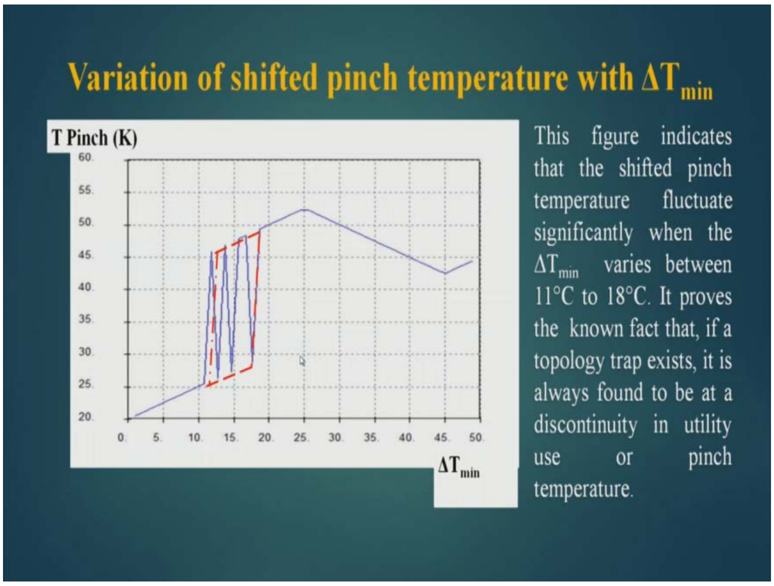
These discontinuities are generated when a HEN handles significantly large latent heat loads over a narrow temperature range. So, this clearly tells that why the topology trap occurs. However, a sharp change in energy targets or pinch temperature many a times make no real difference to energy and area targets, thus does not contribute towards topology trap. What it means that always discontinuities in the energy or the pinch due to delta T minimum does not contribute to topology trap. But however topology trap always occurs when we observe discontinuities in the pinch temperatures or pinch versus delta T minimum plot or energy area or cost versus delta T minimum plots.

(Refer Slide Time: 05:19)



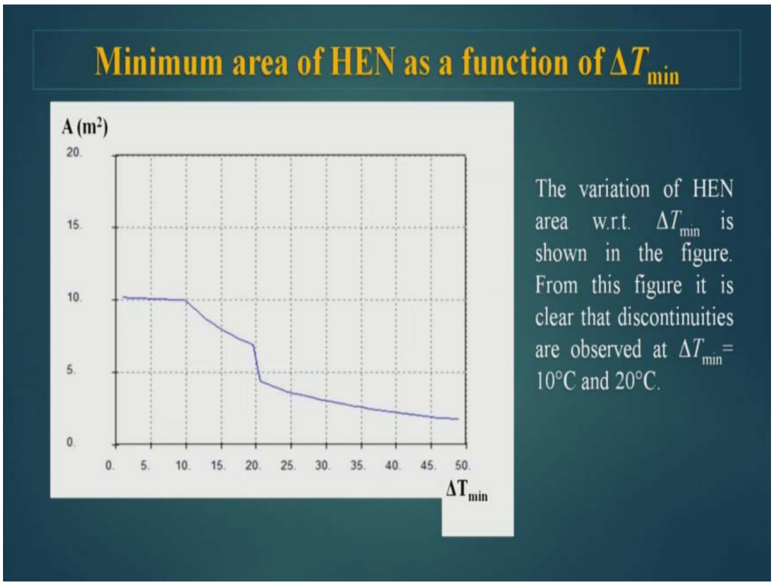
To illustrate the topology trap let us take a stream table data as shown below. So, this is a four stream problem - two hot streams, two colds streams, one hot utility, one cold utility. This data shows topology trap. Now, to plot the TAC values with delta T minimum, we need some more data as the heat transfer coefficients of all streams as given in the right side column. This is heat transfer for all streams, and then some cost data where the utility cost is rupees 280 per mega watt year, and then capital cost data which gives the cost of heat exchanger 2000 plus 2300 A to the power 0.9; where, A is the area of the heat exchanger network. And the payback period is 10 years, and the interest rate is 5 percent or we should say that the life period of the heat exchanger which is used in the heat exchanger network is 10 years and the interest rate is 5 percent. So, using this data we can always calculate the cost targets, we can also calculate the area target and energy target.

(Refer Slide Time: 07:20)



Now let us see that how the pinch temperature changes, when delta T minimum varies. For this, this plot has been created. This clearly shows how the pinch temperature varies with delta T minimum. In this region, we see there is a fluctuation of pinch temperature, when delta T minimum varies, so this is the range. This figure indicates that the shifted pinch temperature fluctuates significantly when the delta T minimum varies between 11 to 18 degree centigrade. It proves the known fact that if a topology trap exists, it is always found to be at the discontinuity in utility uses or pinch temperature. So, here we see that there is a lot of discontinuities in the pinch temperature in this range. So, it is a topology trap problem.

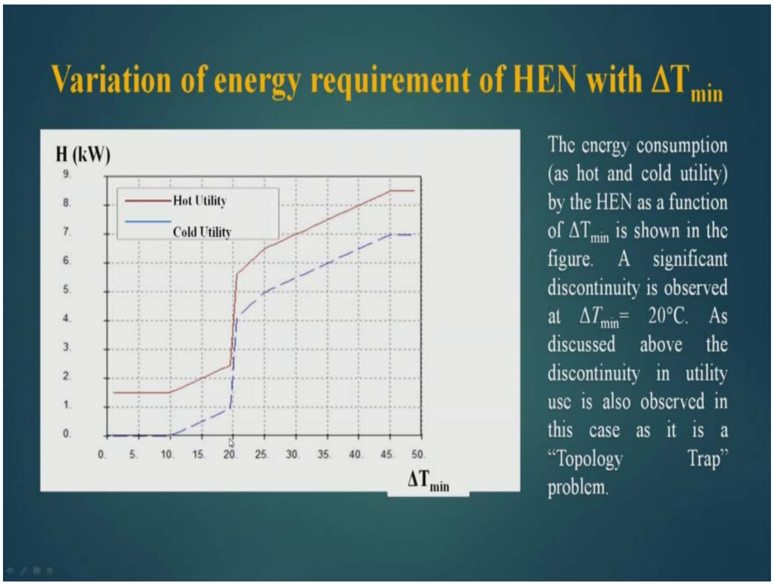
(Refer Slide Time: 08:25)



Let us see the behavior of area with delta T minimum. A topology trap is also visible in the area curve. You see that when it changes from 0 to 10, the area is almost constant, then sudden there is a drop up to this point 10 to 20 delta T minimum and then it slowly decreases. That means, think of a case when your delta T minimum is 19 degree, you are operating at this point, when delta T minimum is 20, you are operating at this point. The whole behavior of the heat exchanger network changes within a degree or so, that means, designing in this zone is dangerous, because due to the fluctuation in the temperature of different streams your delta T minimum can fluctuate.

And if the delta T minimum fluctuates, and goes to this point or comes to this point there is a difference in the area demand for the HEN and hence it can create problems. So, again we see the variation of HEN area with respect to delta T minimum is shown in this figure shows that there is a clear cut discontinuity between the temperature 10 degree centigrade to 20 degree centigrade. So, in the design this range is troublesome range and it may create some problem in the design.

(Refer Slide Time: 10:32)



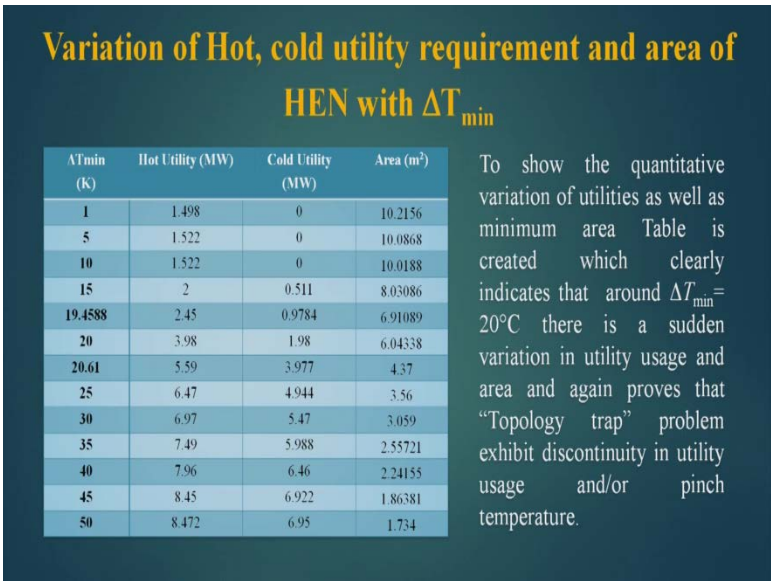
Now let us see variation of energy requirement of HEN with respect to delta T minimum. Now this shows a very very typical curve, the hot utility demand is this, it is all most constant here - and up to this point, the hot utility demand is constant; and almost cold utility demand is zero. And then the hot utility cold utility demand grows linearly and there is a sudden jump in hot utility requirement and cold utility requirement near the 20 degree centigrade, and then they change linearly up to this point and then linearly up to this point and this point. So, this is a very typical behavior of the demand of hot utility and cold utility with respect to delta T minimum. This type of behavior we have not seen in other problems.

So, the energy consumption as hot and cold utility by the HEN as a function of delta T minimum is shown here that is significant discontinuity is observed when delta T minimum is near 20 degree centigrade. As discussed above the discontinuity in utility use is also observed in this case as it is a topology trap problem. Think of a case when the HEN is designed here, and if suddenly, there is a change in delta T minimum due to some reasons some fluctuation in the temperatures of the streams then the demand of hot and cold utility will be at this point. So, the performance of the heat exchanger network will drastically change or it will not be able to perform as per the design. So, for this problem, this temperature zone is very very sensitive and we should not design our heat exchanger network in this zone.

So, it very clearly tells. So, analyses of such type to know the behavior of the heat exchanger network when delta T minimum is changing is very very important. This shows us the zones where we should avoid designing the problem, and such type of problems are more acute, when there is a topology trap. Now here we can see that from this point to this point say up to 10 degree centigrade, this is a threshold problem. I have already told that the threshold problems are those problems where one of the utility is zero. So, we see that from this point to this point, cold utility is zero and that is only a demand for the hot utility.

So, think of a case when I am designing up to 10 degree centigrade, it is a threshold problem. Then suddenly when delta T minimum goes from ten to say near up to 19 degree centigrade or so delta T minimum equal to then it converts into a pinch problem. And then, suddenly it rises to a very high value and then again it behaves like pinch problems. So, this is a special case of problems, which are called topology trap problems.

(Refer Slide Time: 14:54)

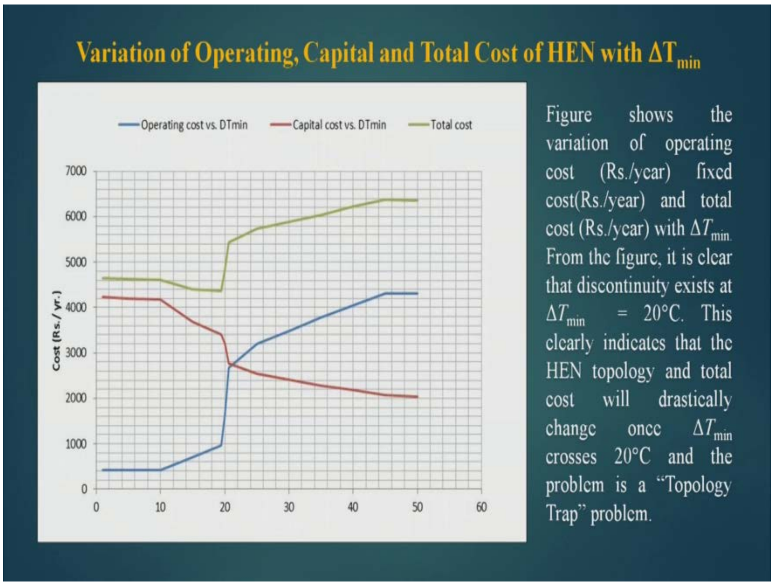


Now let us see the requirement of we have seen that the variation of hot, cold utility requirements and area requirements of the HEN with delta T minimum. And this is very clearly shown by a table where the first column is delta T minimum, and the second column is hot utility requirement, the third column is cold utility requirement and the fourth column is area requirement. So, we see that when we are changing from 1 to 10, the hot utility requirement is almost constant and cold utility requirement is zero. So, this is a threshold problem up to this area requirement is almost constant at 10 meter square.

However, when we go for 15 to say 19 and say up to 20 where requirements slightly increases in hot utility, cold utility requirements also increases, this has become large. And at 20.61 degree centigrade, there is a sudden jump in hot utility and cold utility, but the area drops, and when we go to this then we see that this is increasing and here there is a decreasing area, up to this. So, it is a very very typical behavior and in consistent behavior, when we are talking about topology traps.

To show the quantitative variation of utilities as well as minimum area table is created, which clearly indicates that around delta T minimum equal to 20 degree centigrade. There is a sudden variation in utility usage and area and again proves that the topology trap problems exhibits discontinuity in utility usage and or pinch temperature. So, it again proves that if there is a discontinuity in the usage of the energy or area or the cost or in the pinch temperature, it creates a topology trap.

(Refer Slide Time: 17:42)

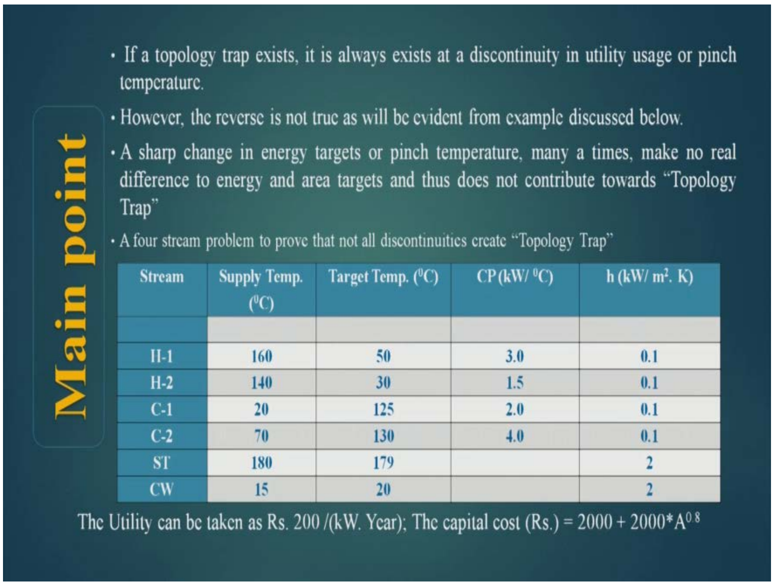


Now if you see for the same problem the variation of operating capital and total cost, this figure is there. So, this is the cost figure and this is the delta T minimum axis. Here we see that this operating cost suddenly lifts up, and this is the fixed cost this suddenly changes here, and in the TAC also we find a sudden raise; that means, if my heat exchange network is here the cost is low and if I change for a degree or so, the cost is high. So, this is a very typical area where functioning of this heat exchanger is very troublesome. So, this type of analysis which is called topology trap, the behavior is called topology trap very clearly shows that which portion of the delta T minimum should be utilized for the design and which portion should not be utilized for design. So, when there is a topology trap, we should be very very cautious for the design.

In the lecture global and stream based delta T minimum contributions also, it has been clearly stated that a design based on global delta T minimum many a times exhibits topology traps. And to avoid this topology trap, a new design method was proposed there which uses the delta T minimum contribution for all the different streams, and there we get a different set of pinch temperature technically. So, to avoid topology trap problems, we can selected a design method in which we are going for delta T minimum contribution for each and every stream of the heat exchanger network.

The figure shows the variation of operating cost, fixed cost and total cost with delta T minimum. From this figure also, it is clear that discontinuities exists at delta T minimum equal to 20 degree centigrade. This clearly indicates that the HEN topology and the total cost will drastically change once delta T minimum crosses 20 degree centigrade and the problem is a topology trap problem. So, one thing was clear to us that if a discontinuity is there in the pinch temperature or a area or cost or energy, when it is plotted with respect to delta T minimum, a topology trap problem may occur. But this that every discontinuity will lead to a topology trap is not always there, the reverse is not true. But topology trap will occur when there will be a discontinuity, but every discontinuity will not lead to topology trap, this is a truth.

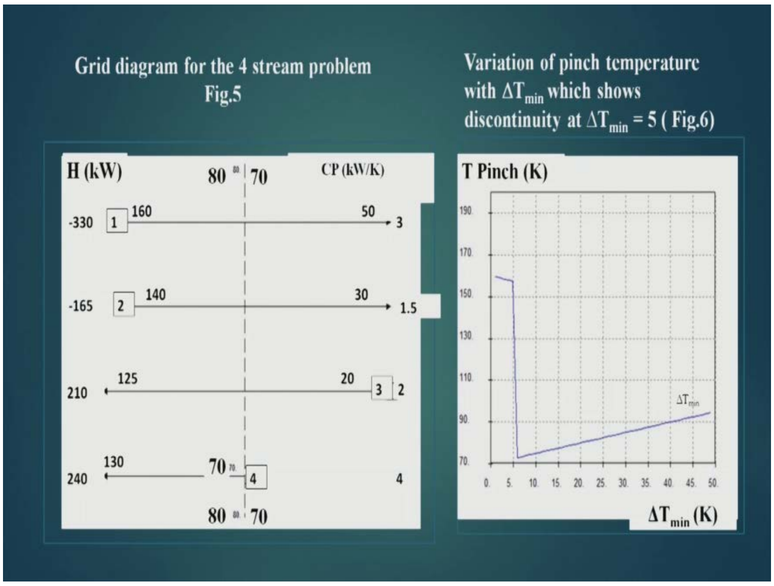
(Refer Slide Time: 22:09)



So, what are the main points. If a topology trap exists, it is always exists at a discontinuity in utility usage or pinch temperature. However, the reverse is not true as will be evident from example discussed below. A sharp change in energy targets or pinch temperature, many a times, makes no real difference to energy and area targets and thus does not contributes towards topology trap. This very clearly says that if a topology trap has to occur then it will occur in the discontinuity, but every discontinuity will not lead to topology trap.

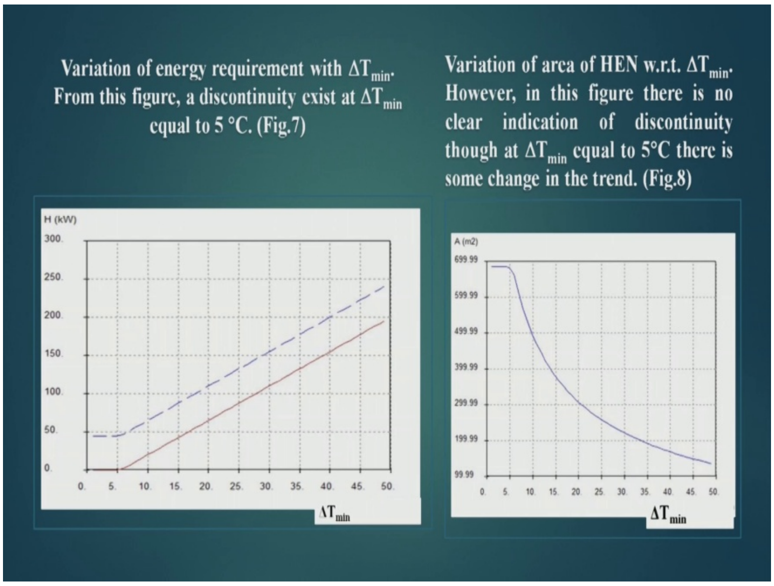
A four streams problem to prove this statement that not all discontinuities lead to topology trap is given below. This is a stream table which will analyze to prove that that not all discontinuities create topology trap. For this purpose, we have taken this stream table, which has got two hot streams, two cold streams, hot utility as stream and cold utility as cold water. These are supply temperature target temperature C p values, and h values, because this is required for area targeting and then there are some cost values are required for costing for cost target. So, utility values are 200 rupees per kilowatt year and capital cost is 2000 plus 20000 A to the power 0.8. So, this cost relations are required for targeting total annual cost as a function of delta T minimum.

(Refer Slide Time: 24:41)



Now if you see the grid diagram of the above problem, the grid diagram is shown here. The pinch temperature is 80 to 70 - that is hot pinch temperature is 80 and cold pinch temperature is 70. Now this problem very clearly shows that it looks like a ordinary problem, and let us see the further analysis of this. So, if we plot the variation of pinch temperature with the delta T minimum, then we see a sudden change in pinch temperature as delta T minimum at five degree centigrade. There is a sudden discontinuity here, very clear discontinuity. However, after that there is no discontinuity. So, there is a chance that the topology trap will occur in this temperature.

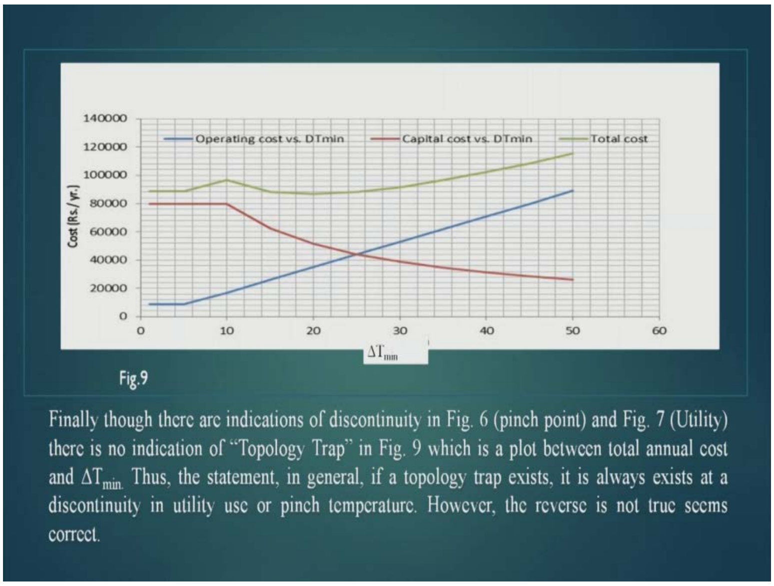
(Refer Slide Time: 26:20)



However, we will see that not all temperature discontinuities will lead to a topology trap. Now if you see the variation of energy requirement with delta T minimum for the above problem then we see that here the utility is changing up to this, the utility is constant, one utility is zero, so there is a threshold problem up to this, and then both the utilities are increasing with delta T minimum. So, here a discontinuity exists at delta T minimum equal to 5, and this discontinuity may be due to the threshold problem. However, we do not see any other discontinuities in the latter part of the delta T minimum.

Similarly, if we plot the area versus delta T minimum, we see that the area remains constant here, because when the delta T minimum is changing from zero to five, the cost of or the hot utility and cold utility requirements are not changing, here we find a constant area up to this and then area slowly decreases. So, what we observe that there is a variation of area of HEN with respect to delta T minimum, however, in this figure there is no clear indication of discontinuity at a delta T minimum equal to five degree centigrade, there is some change in the trend. So, what we see that the discontinuity in the pinch or the discontinuity which is available to some extent or visible to some extent at in the energy requirement or the utility requirement curve at delta T minimum equal to five has not affected the area curve substantially. And hence up till now, there is no visible evidence or visible symptom of a topology trap in this problem.

(Refer Slide Time: 29:28)



Now if we analyze the cost curves then we find that this is the operating cost change. This is the change in fixed cost; that means, up to this 10 degree centigrade or so, the fixed cost it is almost constant; up to five degree or so, the utility cost remains constant, and then the fixed cost decreases slowly. And here also it increases slowly after 5 degree centigrade. And when we see the TAC curve that is total annual cost curve, it remains constant up to this point, and slowly increases and then decreases, and then slowly increases. So, here also there is no visible symptom of a topology trap problem - that means, all the discontinuities do not lead to topology trap.

However, the topology trap will occur in the areas where discontinuities in pinch point or discontinuity in energy consumption pattern or discontinuity in area or the discontinuity cost which are dependent on the discontinuities of other curves takes place. It should be known very clearly that this type of topology trap problem occurs, when the heat exchanger network is handling a large amount of latent heat load within a small interval of temperature. So, the topology trap problems creates problem in the design of HEN, and if it is a topology trap problem then we should be very cautious to fix up the delta T minimum temperature at which the whole heat exchanger will operate, this is one thing.

The second thing is that to avoid topology trap as I have been suggested earlier, we can change our design philosophy or analyses philosophy of process integration problem, and we can go for delta T minimum contribution of individual streams and then it is a chance that topology trap problem will not occur. Finally, there are indication of discontinuities in this figure in pinch point and in figure 7 in the utility, there is no indication of topology trap in the above figure which is a plot between the total annual cost and delta T minimum. Thus, the statement in general, if a topology trap exists, it is always exists at a continuity in utility use or pinch temperature. However, the reverse is not true seems correct.

Thank you.