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

Module - 3
Building Blocks of PINCH Technology
Lecture - 5
Threshold Problems

Welcome to the lecture series on Process Integration. And this lecture will discuss threshold problems. This is module-three, lecture number five.

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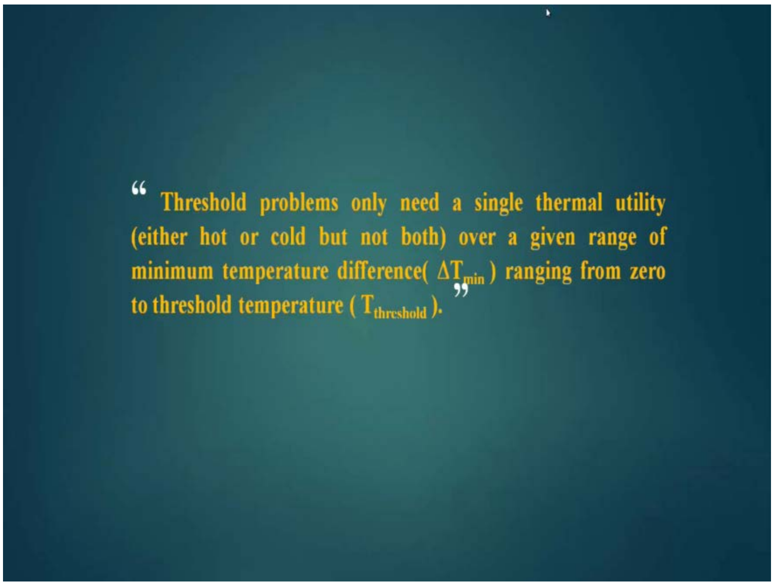

“ Threshold problems only need a single thermal utility (either hot or cold but not both) over a given range of minimum temperature difference(ΔT_{min}) ranging from zero to threshold temperature ($T_{threshold}$). ”

Threshold problems only need is single thermal utility either hot or cold, but not both over a given you range of minimum temperature difference that is delta T minimum ranging from zero to a threshold temperature. So, this is the definition of a threshold problem. Why threshold problems are important to us, this is because they demand only a single thermal utility that may be hot utility or may be cold utility. If the problem demands only hot utility, I have to put a boiler in the industry, and I do not have to put a cooling tower in the industry. So, we save either boiler or cooling tower in such problems, now to find out a problem whether it is threshold problem or not.

Generally, we compute the utilities over a range of delta T minimum starting from zero; and generally we find that after a certain value of delta T minimum the problem starts demanding hot and cold utilities both. But before that it either demands hot utility or cold utility; that means, that for every problem we should try to search whether the problem is threshold problem or not. If you detected to be a threshold problem, it can brings a wings to the industry.

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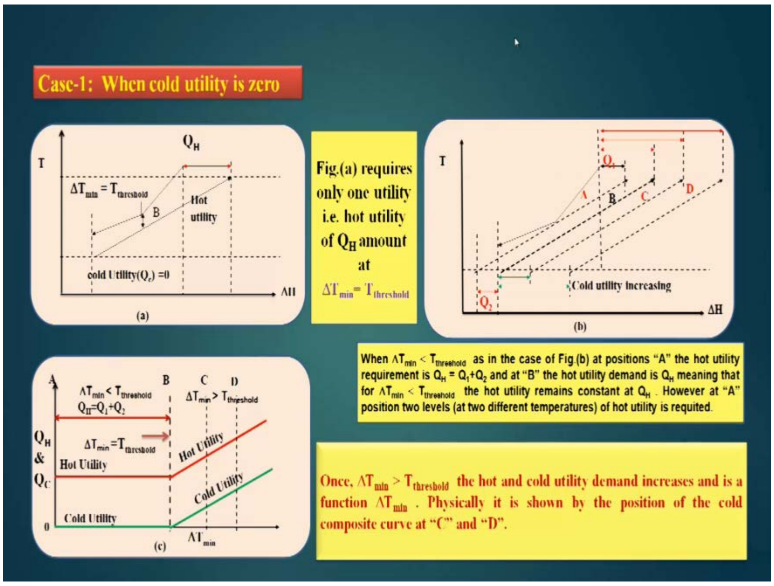

Case-1: When cold utility is zero

Fig.(a) requires only one utility i.e. hot utility of Q_H amount at $\Delta T_{min} = T_{threshold}$

When $\Delta T_{min} < T_{threshold}$ as in the case of Fig.(b) at positions "A" the hot utility requirement is $Q_H = Q_1+Q_2$ and at "B" the hot utility demand is Q_H meaning that for $\Delta T_{min} < T_{threshold}$ the hot utility remains constant at Q_H. However at "A" position two levels (at two different temperatures) of hot utility is requited.

Once, $\Delta T_{min} > T_{threshold}$ the hot and cold utility demand increases and is a function ΔT_{min}. Physically it is shown by the position of the cold composite curve at "C" and "D".

Now let us see in detail what is a threshold problem? And how it is generated. Now in figure – a, we show here a threshold problem which needs only hot utility and demand of cold utility is zero. Now this is in b position of the cold composite curve that is when cold composite curve attends a position b, then the cold utility demand is zero as shown by this. The cold, one end of the composite cold matches with the end of the hot composite curve and hence demand of the cold utility is zero, whereas, there is a demand of hot utility Q H.

Now, if you see here in this figure which is b in this position a position of the composite cold curve, there is demand of hot utility Q 1 and another hot utility Q 2 where Q 1 plus Q 2 is Q H. Now when we shift it to the right hand side a position comes when the cold utility demand is zero, however there is a hot utility demand of Q H. If you shift it further to a position c then we find that there is a cold utility demand from this point to this and as well as there is hot utility demand from this point to this point. Further, if I shift it to d position, there is a cold utility demand from here to here, and there is a hot utility demand from this point to this point.

Now, this can be represented, this movement can be represented here basically when I am shifting the composite cold curve from the hot composite curve, the delta T minimum is changing. And this case, the delta T minimum is almost zero here, and when you shift to the b, this is the delta T minimum. When I shift to c, this is the delta T minimum, and may be when you shift to d position, this is will be the delta T minimum. So, here the hot utility and cold utility are plotted with delta T minimum as a parameter in the x axis. So, we see that when the delta T minimum is changing from zero to a certain value here up to here, which is called the T threshold the cold utility demand is zero; whereas, the hot utility demand is fixed at Q H.

If delta T minimum is less than t threshold Q H is equal to Q 1 plus Q 2 where Q 1 and Q 2 may vary, but here summation Q 1 and Q 2 will remain constant at Q H. So, the hot utility demand is fixed at Q H up to the three T threshold point. When the delta T minimum is greater than T threshold then we see that the cold utility demand as well as hot utility demand increases.

This is the line, where you see the hot utility is increasing, here also the cold utility is increasing. It clearly indicates that if I am operating my ((Refer Time: 07:08)) in this zone that is below T threshold; if I am able to operate my heat exchanger network with delta T minimum which is less than T threshold then I will be requiring only hot utility and no cold utility. This means that one has to put the boiler only for generation of the steam or a heater for the generation of hot water or hot oil to service the hot utility demand and he has not to go for any generation of cold utility using a cooling tower. So, a lot of saving can take place.

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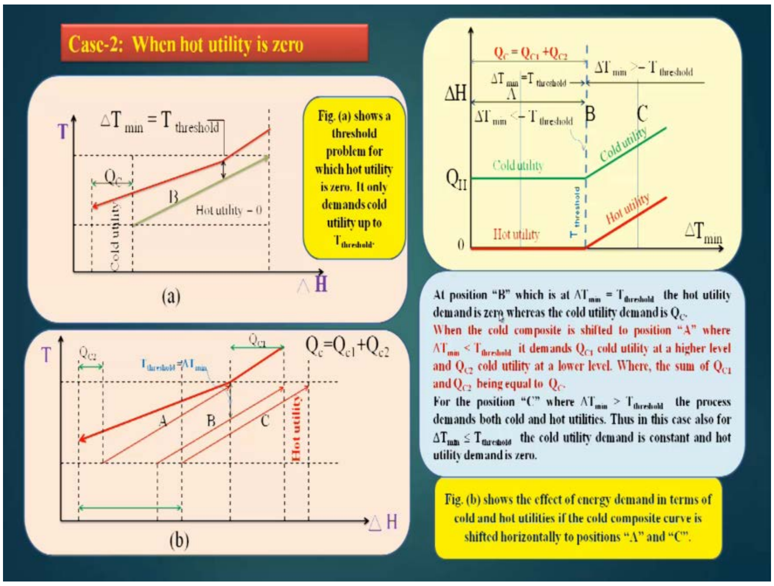

Case-2: When hot utility is zero

Fig. (a) shows a threshold problem for which hot utility is zero. It only demands cold utility up to $T_{threshold}$.

At position "B" which is at $\Delta T_{min} = T_{threshold}$ the hot utility demand is zero whereas the cold utility demand is Q_C.

When the cold composite is shifted to position "A" where $\Delta T_{min} < T_{threshold}$ it demands Q_{C1} cold utility at a higher level and Q_{C2} cold utility at a lower level. Where, the sum of Q_{C1} and Q_{C2} being equal to Q_C.

For the position "C" where $\Delta T_{min} > T_{threshold}$ the process demands both cold and hot utilities. Thus in this case also for $\Delta T_{min} \leq T_{threshold}$ the cold utility demand is constant and hot utility demand is zero.

Fig. (b) shows the effect of energy demand in terms of cold and hot utilities if the cold composite curve is shifted horizontally to positions "A" and "C".

Now, let us see the second case, when hot utility is zero, but there is a demand of cold utility. This figure – a, shows that this is the composite hot curve and this is the composite cold curve. This end of the composite hot curve matches with this end of the composite cold curve showing that there is no requirement of hot utility; however, there is requirement of cold utility here, which is given by Q C, which is difference between this point and this point in the horizontal axis. Because this horizontal axis is delta H, so this difference will give the demand of the cold utility.

Now, if delta T m that is delta T minimum is changed, here we see that this curve is generated when we plot delta H versus delta T minimum up to this point, where delta T minimum is equal to T threshold, the requirement of hot utility is zero, whereas the requirement of cold utility is there. This will be Q C and Q C is equal to Q C 1 plus Q C 2. After this T threshold, there will be a demand of cold utility as well as hot utility. So, if delta T minimum is less than T threshold, we are end this zone; and when delta T minimum is greater than T threshold we are end this zone. So, if the heat exchanger network is designed in such a fashion that it operates with delta T minimum less than T threshold, then in this case it will be requiring only cold utility and not hot utility and that to be amount of cold utility requirement will be equal to Q C.

So, in this case only one will require a cooling tower to supply the cold water and not a boiler to supply any hot utility or the utility heating. Now this source let add this point the hot utility demand is zero, but there is cold utility demand of Q C when it shifts horizontally to this point then the cold utility demand here is Q C 2 and here this Q C 1, where Q C 1 plus Q C 2 is equal to Q C. One should observe this that these two cold utility demands are not add the same temperature, this it act Q C that higher temperature and this Q C 2 is at a lower temperature. So, it will be demanding two cold utilities at two different temperatures. May if I shift this to this point c then what happens, there is hot utility demand which will be given by distance between this point and this point and the cold utility demand is from this point to this point. So, the hot utility demand emerges out after it crosses T threshold and then the cold utility demand also increases.

So, this clear a case when there is hot utility demand is zero, and there is a cold utility demand and when I am shifting the cold composite curve to a different positions which marks different delta T minimum then how the cold utility amount and hot utility amount are changing. And it very clearly shows that up to T threshold, the cold utility demand remains constant, whereas the hot utility demand remains zero and after T threshold both hot utility and cold utility demands grow, and indicating that if we are able to operate the heat exchanger network below T threshold, when the hot utility demand is zero at T threshold then we consider a plot.

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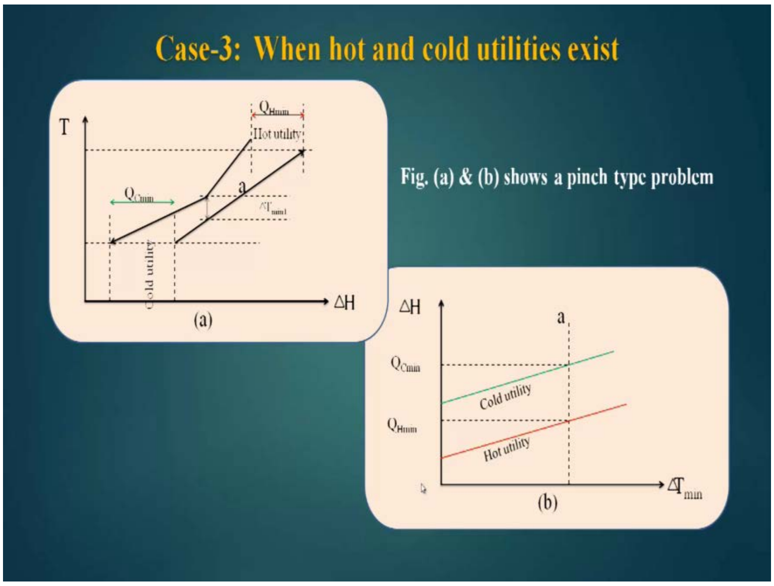

Case-3: When hot and cold utilities exist

Fig. (a) & (b) shows a pinch type problem

Now you take a third case, when there exist hot utility demand and cold utility demand as well. So, if I shift this cold utility - cold composite curve, towards this and away from this; this is how the cold utility demand will increase and hot utility demand will increase with delta T minimum. So, this is not a threshold problem, because at T minimum delta T minimum equal to zero, there is a demand of hot utility and there is a demand of cold utility, and when delta T minimum increases from zero onwards, the cold utility demand and hot utility demand increases. That means, we will not have any zone of delta T minimum where either cold utility demand or hot utility demand will remain zero, and hence, it is not a threshold problem.

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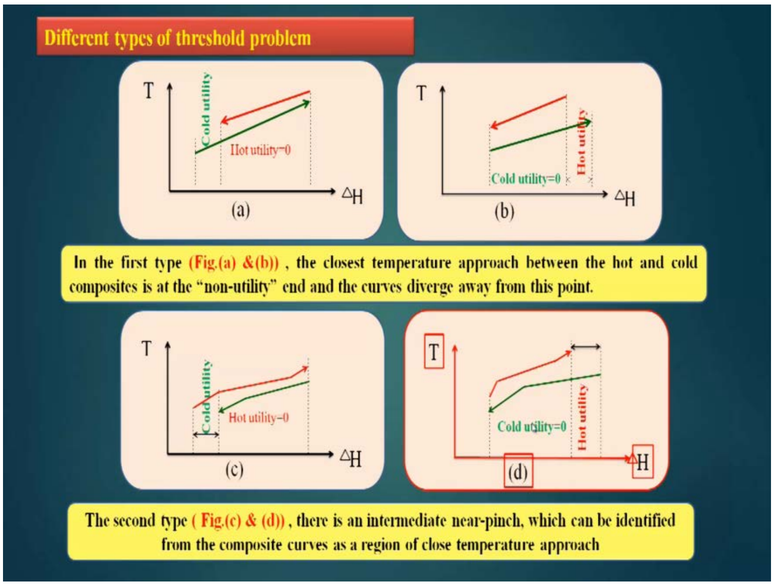

Different types of threshold problem

In the first type (Fig.(a) &(b)) , the closest temperature approach between the hot and cold composites is at the "non-utility" end and the curves diverge away from this point.

The second type (Fig.(c) & (d)) , there is an intermediate near-pinch, which can be identified from the composite curves as a region of close temperature approach

Now let as see there are different types of threshold problems. Now, figure – a, shows this, this is a composite hot curve and this is a composite cold curve, but the distance between this two is minimum here at non-utility end this is a non-utility end because here the demand of hot utility zero. So, this is a non-utility end, it is minimum here. In the same manner, if you see here here the cold utility zero, because the composite cold curves one end is matches with the composite hot curves the other end. So, here the demand of cold utility zero and the delta T minimum is minimum at this end. In this case, we see that the there is cold utility demand and here the hot utility requirement is zero, but the delta T minimum at this end is not minimum, it is somewhere minimum at this point.

Similarly, there can be case when there is a cold utility demand is zero at this case, but the delta T minimum able of will here is not the minimum. If I consider the value of delta

T minimum which is varying from this to this, and there is a hot utility demand here. So, in the first type figure a and b, the closest temperature approach between the hot and cold composite, it is at the non-utility end, and the curves diverge from this point. Whereas, in the second type of problems that is figure c and d, there is an intermediate near pinch, which can be identified from the composite curve as a region of close temperature approach.

Now, let us see what is the capital energy trade of for threshold problems; that means, of the cost changes for threshold problems, because finally everything has to be converted into the cost or you can say total annual cost. And decision will be taken for the design of heat exchanger network, which will give minimum tag that is total annual cost. And we will see that at a particular delta T minimum or for a range of delta T minimum, the total annual cost remains minimum. And hence the behavior of the cost in which may be capital cost or it may be operating cost or it is may be a mix up these two which the total annual cost, we will see that how this cost varies with delta T minimum.

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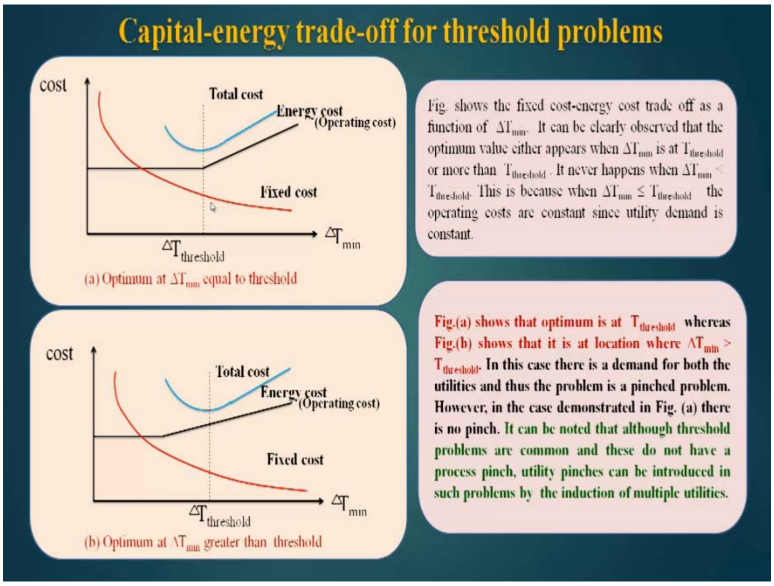

Capital-energy trade-off for threshold problems

Fig. shows the fixed cost-energy cost trade off as a function of ΔT_{min}. It can be clearly observed that the optimum value either appears when ΔT_{min} is at $T_{threshold}$ or more than $T_{threshold}$. It never happens when $\Delta T_{min} <$ $T_{threshold}$. This is because when $\Delta T_{min} \leq T_{threshold}$ the operating costs are constant since utility demand is constant.

Fig.(a) shows that optimum is at $T_{threshold}$ whereas Fig.(b) shows that it is at location where $\Delta T_{min} >$ $T_{threshold}$. In this case there is a demand for both the utilities and thus the problem is a pinched problem. However, in the case demonstrated in Fig. (a) there is no pinch. It can be noted that although threshold problems are common and these do not have a process pinch, utility pinches can be introduced in such problems by the induction of multiple utilities.

Now this is the operating cost which changes from this point to this point and remains constants to this to this and; obviously, this is the t threshold; up to T threshold the utility demand remains constant, whether it is a hot utility demand or a cold utility demand. So, the operating cost remains constant up to the T threshold and then it increases, but the fixed cost decreases when I increase the delta T minimum, I am providing more delta T;

that means, driving force and hence in general the area decrease for a constant heat transfer. So, once the area increased in delta T minimum the fixed cost decreases. So, we get a total cost figure like this, where minimum matches with the T threshold - this is one case when optimum cost matches with the T delta Tm threshold, there can be another case where it does not match.

So, we go for the another case, where the T operating cost moves like this, where this is the T threshold point and remains constant up to T threshold point and then it increases as; obviously, we have seen and then the fixed cost decreases with delta T minimum. The explanation is the same when delta T minimum which is the minimum driving cost available in the heat exchanger network increases then the area decreases for a fixed value of Q and fixed value of U. And when we combine this two cost then we get a total cost, and this is the total cost figure, but here the most important is that the minimum of the total cost figure does not match with the T threshold, so it is greater than the T thresholds.

In the figure b shows that optimum is at optimum location is that delta T minimum is greater than T threshold that is optimum lies in a area where delta T minimum is greater than T threshold. And this case there is a demand for both the utilities and thus the problem is pinched problem. So, if we come across such problems at this point, there is a demand of hot utility as well as cold utility, because delta T minimum is greater than T threshold. And thus this problem works as pinched problem. However, in the upper case, there is no pinch in this is not a pinch problem and it can be noted that all the threshold problems are common and this do not have a process pinch, utility pinch can be introduce in such problem by the induction of multiple utilities.

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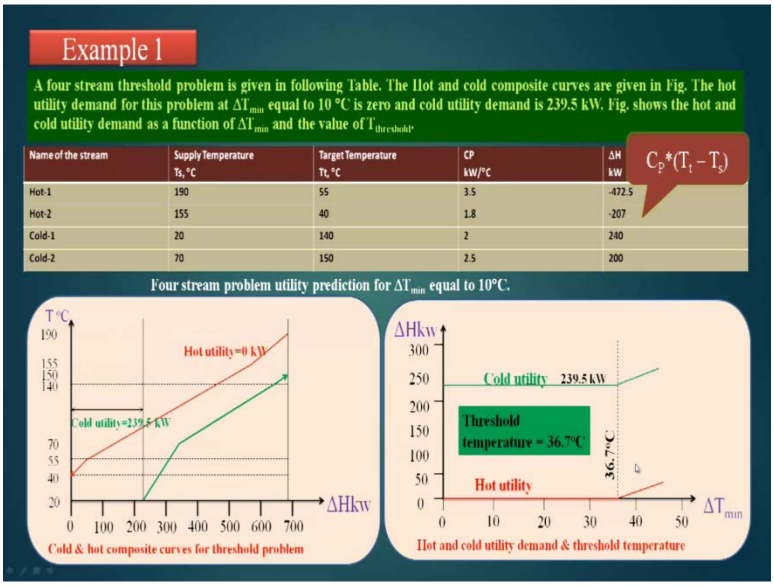

Example 1

A four stream threshold problem is given in following Table. The Hot and cold composite curves are given in Fig. The hot utility demand for this problem at ΔT_{min} equal to 10 °C is zero and cold utility demand is 239.5 kW. Fig. shows the hot and cold utility demand as a function of ΔT_{min} and the value of $T_{threshold}$.

Name of the stream	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH kW
Hot-1	190	55	3.5	-472.5
Hot-2	155	40	1.8	-207
Cold-1	20	140	2	240
Cold-2	70	150	2.5	200

$C_P*(T_t - T_s)$

Four stream problem utility prediction for ΔT_{min} equal to 10°C.

Cold & hot composite curves for threshold problem

Hot and cold utility demand & threshold temperature

Now, let us see this with problem. So, we take a four stream threshold problem given here. There are two hot streams and two cold streams, and the delta H is computed by multiplying the cp value with delta T values; that means, this CP value. So, 207 is computed by taking 1.8 as CP value, this would be capital CP, CP values and then multiply it with 155 minus 40. So, this comes out be 207. So, for this problem when we plot our composite hot and composite cold, we find that this end does not required hot utility. So, the hot liquid utility is zero for this problem, whereas there is a requirement of 239.5 kilo watt of cold utility and when we take delta T minimum is equal to 10 degree centigrade. So, at 10 degree centigrade this is a threshold problem.

Now, if we plot the demand of cold utility as well as hot utility as a function of delta T minimum. So, at a the y axis delta H and the x axis delta T minimum, if we plot this and vary this delta T minimum and we have seen that at 10 degree centigrade when delta T minimum is equal to 10 degree centigrade, there is a cold utility requirement and hot utility requirement is zero. This is being shown here. So, when you change this we find that up to 36.7 degree centigrade, the hot utility demand is zero; and cold utility demand is fixed at 239.5 kilo watt. After this temperature the demand of hot utility as well as cold utility increases, and hence this problem clearly states that the T threshold is 36.7 degree centigrade.

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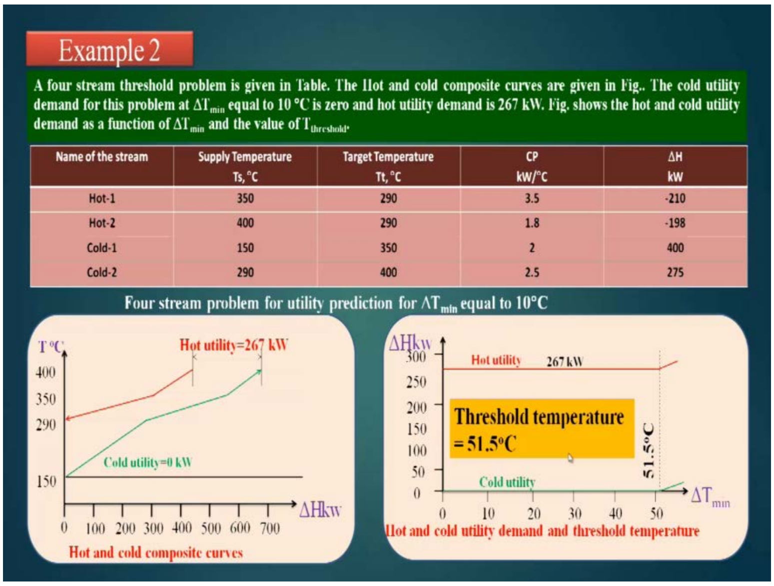

Example 2

A four stream threshold problem is given in Table. The Hot and cold composite curves are given in Fig.. The cold utility demand for this problem at ΔT_{min} equal to 10 °C is zero and hot utility demand is 267 kW. Fig. shows the hot and cold utility demand as a function of ΔT_{min} and the value of $T_{threshold}$.

Name of the stream	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH kW
Hot-1	350	290	3.5	-210
Hot-2	400	290	1.8	-198
Cold-1	150	350	2	400
Cold-2	290	400	2.5	275

Four stream problem for utility prediction for ΔT_{min} equal to 10°C

Now, we take another problem, which is also a four stream problem to find out what is the T threshold value. Here this problem clearly shows when we plot the composite hot and composite cold that the cold utility demand is zero. However, there is a hot utility demand of 267-kilo watt; and this happen when delta T minimum is equal to 10 degree centigrade. Now to find out the value of T threshold we have to plot this curve several times with different delta T minimum, here is the vertical distance is delta T minimum here. So, by shifting this curve right hand side or left hand side parallel to this axis, we can generate the hot utility requirement and cold utility requirement. And if we do so and plot the hot utility requirement and cold utility requirement at different delta T minimum, we can generate this plot, which is between delta H and delta T minimum.

Here we see that when delta T minimum changes from 0 to say 51.5 degree centigrade, up to this the cold utility demand or zero, where the hot utility demand is fixed at 267 kilo watt. This clearly tells that if the cane is designed in such a way that delta T minimum is within 51.5 degree centigrade then it will be requiring only hot utility and no cold utility. The delta T minimum figure of 51.5 degree centigrade is a very high figure and most of the heat exchanger networks can be designed within this delta T minimum.

So, we should try to design the heat exchanger network within this region, and we should not go to this region, because this will increase our operating cost by demanding hot as well as cold utility. And for this purpose we have to either purchase the cold utility from outside or we have to keep cooling towers which will increase our fixed cost as well as operating cost. So, it is advisable to design the cane within this limit. So, when we plot this it clearly tells that my T threshold temperature is 51.5 degree centigrade.

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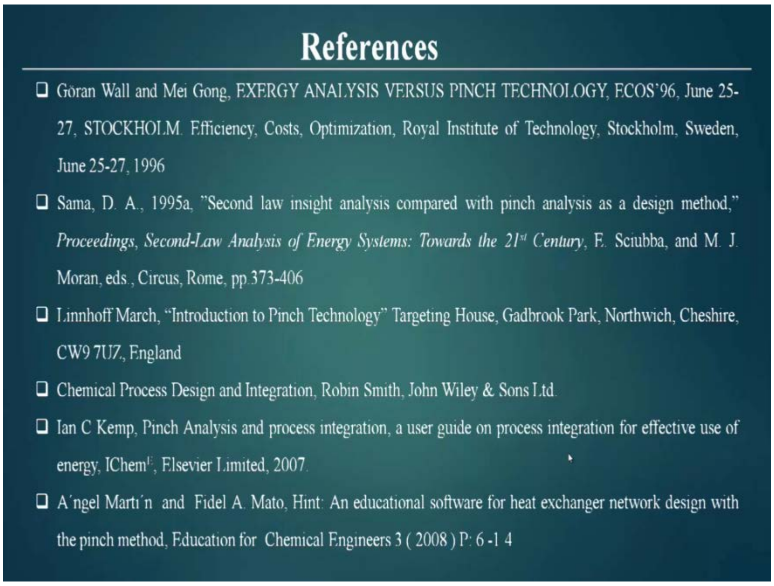

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These are the references, and thank you.