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

Module - 4
Targeting
Lecture - 12
Global and Stream specific delta T Min and its Relevance

Welcome to the lecture series on process integration, the topic of the lecture is global and stream specific, delta T minimum and its relevance delta T minimum is a very important factor. In the design of heat exchanger networks delta T minimum can be accommodate in two, in the first way in which it is being used in pinch analysis is called global delta T minimum. That means, we fix up a delta T minimum which is for the whole problem and try to adhere to this delta T minimum.

The other way of fixing delta T minimum can be of stream specific, that means if the heat transfer coefficient of the stream is high it can operate at a lower delta T minimum. The heat transfer coefficient is less than it can be operated at a higher delta T minimum to control the area. For example, if it is a liquid stream that means heat transfer is taking place between two liquid streams, and they have sufficiently large heat transfer coefficient then delta T minimum or delta T for these two streams should be less. If there are two gaseous streams, their heat transfer coefficient is less then we have to take high value of delta T for the design, so that area is comparatively less.

So, this type of thought clearly tells that the delta T minimum or the delta T between two streams should be a function of their respective heat transfer coefficient. Rather than taking a global delta T minimum, we should go for the stream specific delta T minimum what we are going to gain. If I go for a stream specific delta T minimum, the main job of pinch analysis is to distribute the driving force properly throughout the design.

This we will see in the later part of this lecture that by taking stream specific delta T minimum, the distribution of the driving force becomes better in comparison to a case when delta T minimum is global. Let us analyze the delta T minimum, for this we have taken a force stream problem and the hot composite curve is shown by this and cold composite curve can be shown by this. We are taking vertically transfer and this is a place where the hot composite curve and the cold composite curve distance is minimum.

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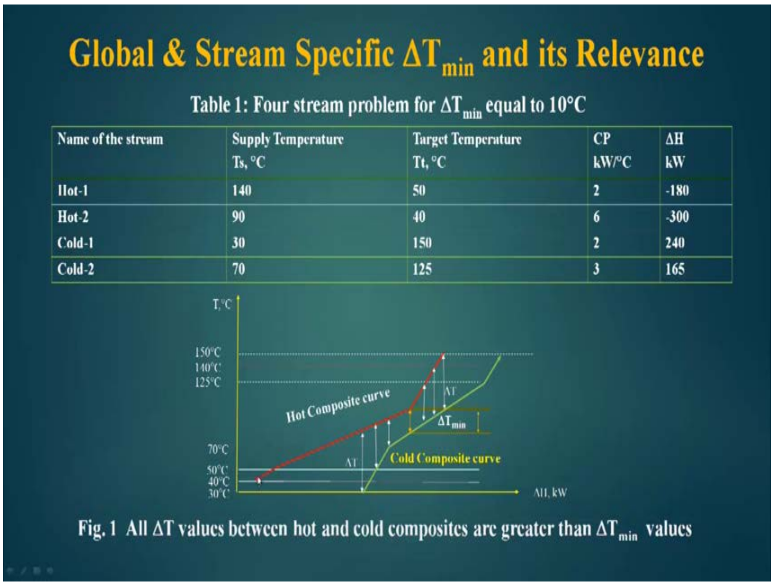

Global & Stream Specific ΔT_{min} and its Relevance

Table 1: Four stream problem for ΔT_{min} equal to 10°C

Name of the stream	Supply Temperature Ts, °C	Target Temperature Tt, °C	CP kW/°C	ΔH kW
Hot-1	140	50	2	-180
Hot-2	90	40	6	-300
Cold-1	30	150	2	240
Cold-2	70	125	3	165

Fig. 1 All ΔT values between hot and cold composites are greater than ΔT_{min} values

This minimum distance is called delta T minimum for this problem, here we see that when you go away from the pinch the delta T that is driving force between the hot composite curve and cold composite curve increases. So, when we move in this direction away from the pinch, on the move away from the pinch in this direction the driving force increases.

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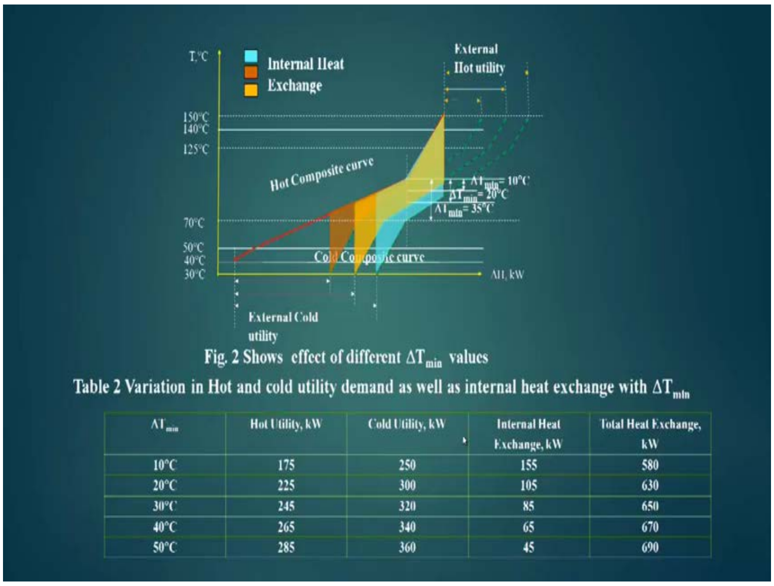

Fig. 2 Shows effect of different ΔT_{min} values

Table 2 Variation in Hot and cold utility demand as well as internal heat exchange with ΔT_{min}

ΔT_{min}	Hot Utility, kW	Cold Utility, kW	Internal Heat Exchange, kW	Total Heat Exchange, kW
10°C	175	250	155	580
20°C	225	300	105	630
30°C	245	320	85	650
40°C	265	340	65	670
50°C	285	360	45	690

This is an example where we concede if the delta T minimum is increasing then what happens to the hot utility cold utility and internal exchange and the total heat transacted.

For this purpose, the cold composite can be shifted away from the hot composite curve, so that the delta T minimum increases in this table number 2. You see that, if you are taken delta T minimum as 10 degrees centigrade, the hot utility requirement is 175, the cold utility requirement is 250, and the internal heat exchange is 155. The total heat exchange which is the sum of these three is 580 kilo Watts. However, when we change delta T minimum from 10 to 20, the hot utility requirement increases from 175 to 225, cold utility requirement increases from 250 to 300.

Internal heat exchange decreases from 155 to 105 and the total heat exchange increases from 580 to 630. Similarly, when we change from 20 degree to 30 degree, the hot utility requirement rises to value 245, the cold utility again rises to 320 units and the exchange drops down to 85 exchange and total heat exchange increases to 650. This very clearly indicates that if I increase delta T minimum, the hot utility demand increases, the cold utility demand increases, the internal heat exchange decreases and total heat exchange increases. Now, this is a very interesting fact, generally it is presumed that when the driving force increases the area requirement is less because a is equal to q divided by u delta T l m.

So, if delta T l m is increasing then area will decrease, however for a heat exchanger network case, we see that if the delta T is increasing total heat transfer also increases, that means q is also increasing. So, in such a case a is equal to q divided by u delta T l m, so when delta T l m is increasing then q is also increasing. So, the deduction in the area by increasing delta T m l m is not that much because q is increasing which is increasing the area of the heat exchange. So, the benefit is partial and not completes this we have to keep in mind.

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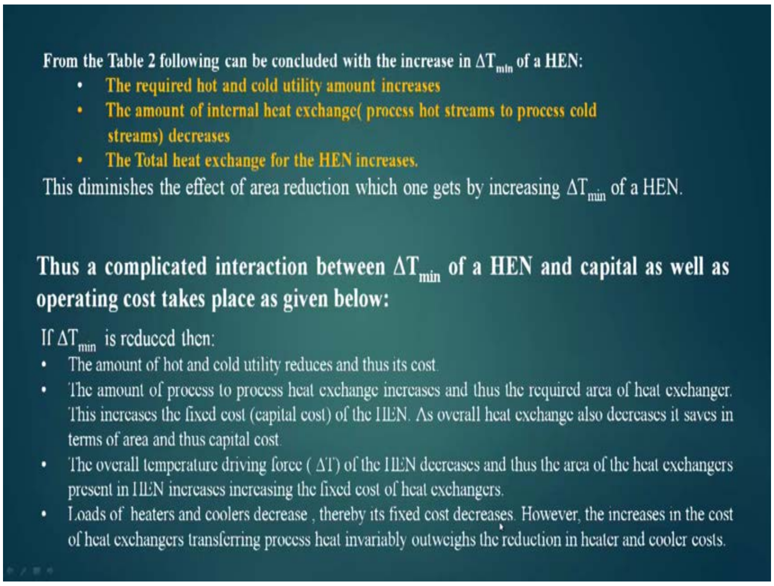

From the Table 2 following can be concluded with the increase in ΔT_{min} of a HEN:

- The required hot and cold utility amount increases
- The amount of internal heat exchange(process hot streams to process cold streams) decreases
- The Total heat exchange for the HEN increases.

This diminishes the effect of area reduction which one gets by increasing ΔT_{min} of a HEN.

Thus a complicated interaction between ΔT_{min} of a HEN and capital as well as operating cost takes place as given below:

If ΔT_{min} is reduced then:

- The amount of hot and cold utility reduces and thus its cost.
- The amount of process to process heat exchange increases and thus the required area of heat exchanger. This increases the fixed cost (capital cost) of the HEN. As overall heat exchange also decreases it saves in terms of area and thus capital cost.
- The overall temperature driving force (ΔT) of the HEN decreases and thus the area of the heat exchangers present in HEN increases increasing the fixed cost of heat exchangers.
- Loads of heaters and coolers decrease , thereby its fixed cost decreases. However, the increases in the cost of heat exchangers transferring process heat invariably outweighs the reduction in heater and cooler costs.

So, to conclude from the table two the following can be concluded the required hot and cold utility amount increases. With increasing delta T minimum for a HEN, the amount of internal heat exchange that is process hot streams to process cold streams decreases and the total heat exchange. For the HEN increases, this diminishes the effect of area reduction which one gets by increasing delta T minimum of a HEN.

Basically, the concept that if we increase delta T minimum then area will decrease is based on constant q value and not for a q which is increasing with increase in delta T minimum. Thus, a complicated interaction between delta T minimum of a HEN and capital as well as operating cost takes place as given below. So, we see that the reaction between or the interaction between delta T minimum of a HEN and its capital components are very critical it cannot be explained very easily.

So, let us see that what are the different interaction parameters, now if delta T minimum is reduced then what happens the amount of hot and cold utility reduces and thus its cost. So, the utility costs reduces the second point, the amount of process to process heat exchange increases and thus the required area of heat exchangers which will be utilized for this purpose will increase.

Thus, the fixed cost of the capital cost of the HEN will increase as overall heat exchange also decreases its saves in terms of area. Thus, capital cost because we have seen that if delta T minimum decreases, the overall heat exchange which has got three components the hot utility exchange, the cold utility exchange area plus the internal heat exchange area decreases.

The overall temperature driving force delta T of the HEN decreases and thus the area of the heat exchangers present in HEN increases. Thus, the fixed cost of heat exchanger network also increases the load of heaters and coolers decreases because when we decrease delta T minimum the amount of hot utility and cold utility decreases. Thus, the size of the heater and cooler also decreases, thereby its fixed cost decreases. However, the increase in the cost of heat exchangers transferring processed heat invariably out ways, the reduction of the area of heater and cooler this we should keep in mind.

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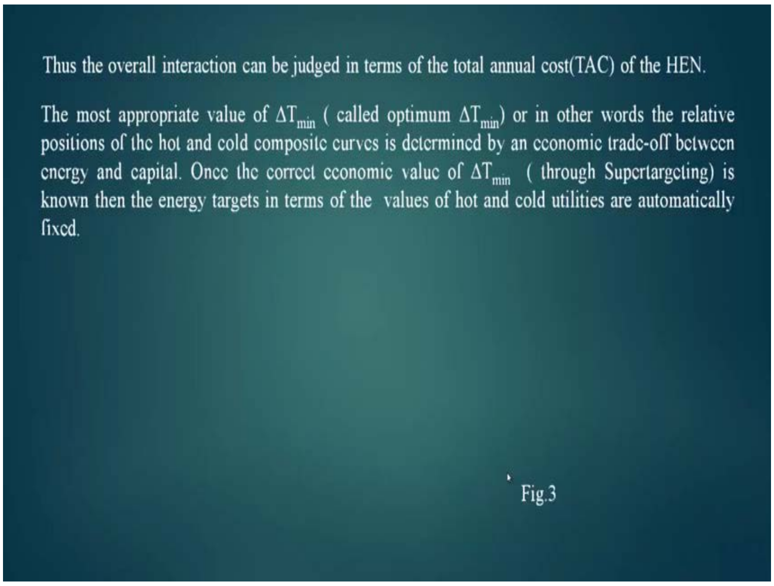

Thus the overall interaction can be judged in terms of the total annual cost(TAC) of the HEN.

The most appropriate value of ΔT_{min} (called optimum ΔT_{min}) or in other words the relative positions of the hot and cold composite curves is determined by an economic trade-off between energy and capital. Once the correct economic value of ΔT_{min} (through Supertargeting) is known then the energy targets in terms of the values of hot and cold utilities are automatically fixed.

Fig.3

Thus, the overall interaction can be judged in terms of the total annual cost when there is a very critical or a complex interaction, then all the interactions will affect cost in different ways. Some parameters of interaction will increase cost some parameters of interaction will decrease cost. In such a scenario, how to find out in which way the interaction is moving better is that we should go for a cost computation T A C which is affected by the interaction parameters. Then in that, we will be able to combine all the factors for affect of all the factors in the T A C and it will convert into a single factor.

We can very easily see the effect of interaction, the most appropriate value of delta T minimum called optimum delta T minimum are. In other words the relative positions of the hot, and cold composite curves is determined by an economic tradeoff between the energy and capital once. The correct economic value of delta T minimum through super targeting is known, and then the energy targets in terms of hot and cold utilities are automatically fixed. If delta T minimum is fixed, then hot utility and cold utility then heat exchange between the hot streams and cold streams all are fixed, so finally we get a plot like this.

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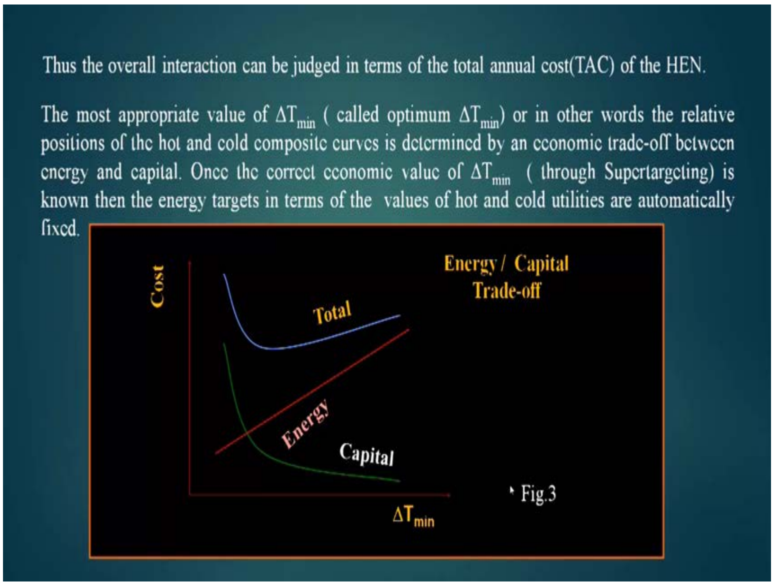

Thus the overall interaction can be judged in terms of the total annual cost(TAC) of the HEN.

The most appropriate value of ΔT_{min} (called optimum ΔT_{min}) or in other words the relative positions of the hot and cold composite curves is determined by an economic trade-off between energy and capital. Once the correct economic value of ΔT_{min} (through Supertargeting) is known then the energy targets in terms of the values of hot and cold utilities are automatically fixed.

Fig.3

Where when delta T minimum is increasing capital cost is decreasing, but energy cost is increasing and the total cost is taking a uni model side.

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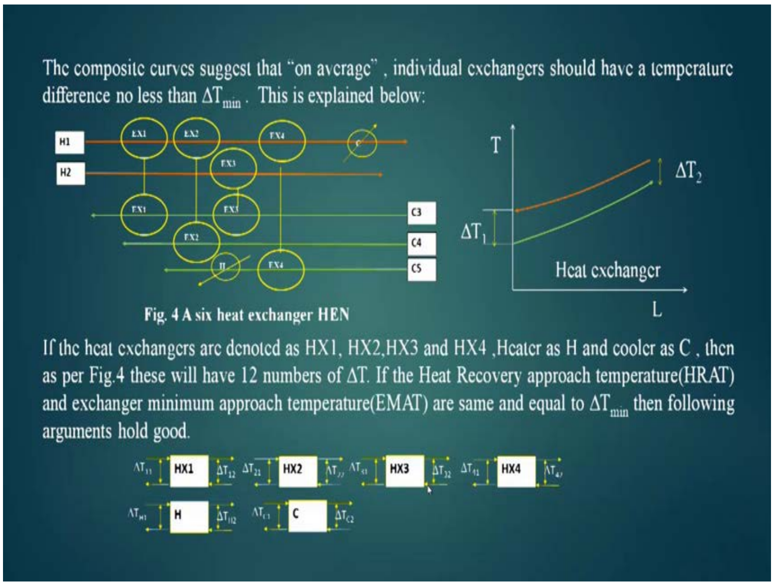

The composite curves suggest that "on average" , individual exchangers should have a temperature difference no less than ΔT_{min} . This is explained below:

Fig. 4 A six heat exchanger HEN

If the heat exchangers are denoted as HX1, HX2,HX3 and HX4 ,Heater as H and cooler as C , then as per Fig.4 these will have 12 numbers of ΔT. If the Heat Recovery approach temperature(HRAT) and exchanger minimum approach temperature(EMAT) are same and equal to ΔT_{min} then following arguments hold good.

Now, let us see what is delta T minimum further we prove into this to saw this we have plotted six heat exchangers which are taking part. In the heat exchanger network for single heat exchangers, the temperature profiles are shown by the right hand side figure. This where temperature profiles are plot T and L X or delta H X, you see that the cold plots temperature is increasing from here to here and the hot plots temperature is dropping down from here to here. So, we have two delta T's available at this end and this end, so the delta T which is available at this end we called it delta T 2 and this end is delta T 1.

So, what we conclude that every heat exchangers we will have two delta T values, so if the heat exchangers are denoted at heat exchanger 1 2 3 4 5 6 and heaters are denoted as H and coolers by C, then as per the figure 4 we will have 12. The numbers of delta T is because every heat exchanger will have two delta T's in that inlet and outlet. So, 12 heat exchangers, 6 heat exchangers will have 12 delta T values.

If you presume that the heat recovery approach temperature and the exchanger minimum approach temperature are same and equal to delta T minimum. Then following arguments will prove what is that argument every heat exchanger will have two delta T's like heat exchanger H X 1 has delta T 1 1 and delta T 1 2 heat exchanger two has delta T 2 1 delta T 2 2 like this.

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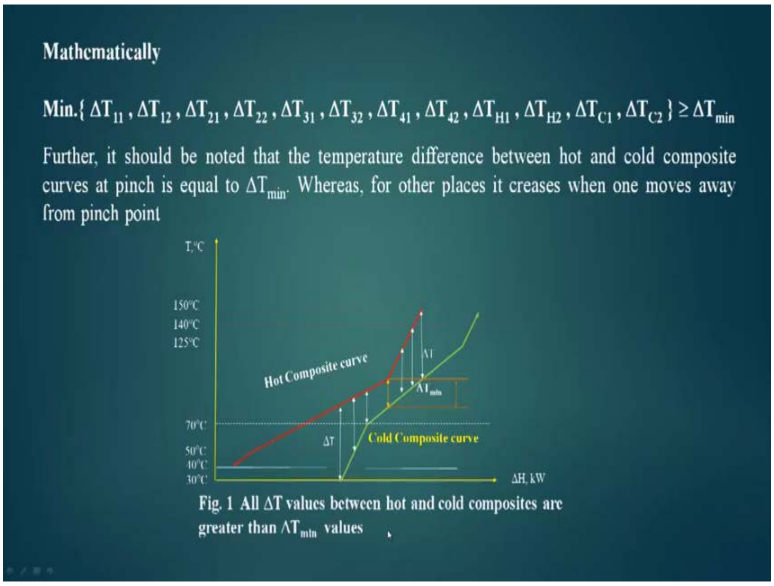

Mathematically

Min.{ $\Delta T_{11}, \Delta T_{12}, \Delta T_{21}, \Delta T_{22}, \Delta T_{31}, \Delta T_{32}, \Delta T_{41}, \Delta T_{42}, \Delta T_{H1}, \Delta T_{H2}, \Delta T_{C1}, \Delta T_{C2}$ } $\geq \Delta T_{min}$

Further, it should be noted that the temperature difference between hot and cold composite curves at pinch is equal to ΔT_{min}. Whereas, for other places it creases when one moves away from pinch point

Fig. 1 All ΔT values between hot and cold composites are greater than ΔT_{min} values

So, mathematically you can write the minimum delta T 1 1, delta T 1 2, delta T 2 1, delta T 2 2, delta T 3 1, delta T 3 2, delta T 4 1 so on. So, for these twelve values minimum this should be greater than or equal to delta T minimum, it should not be less than delta T minimum in anyway. So, if this condition is satisfied we say that delta T minimum is not violated and if it is not satisfied then we say that delta T minimum condition is violated in the design of the heat exchangers network. So, when we are designing for a delta T minimum given delta T minimum which is a global delta T minimum we will ensure that all the delta T's of the heat exchangers should be greater or equal to this.

Near the pinch, we will find that the pinch exchangers will have at least one side of delta T equal to delta T minimum. Further, it should be noted that the temperature different between the hot and cold composite curves at pinch is equal to delta T minimum. We have seen here that this difference is delta T minimum and delta T minimum values or the difference values are more than the delta T minimum when we go away from the pinch this side also. When we go away from the pinch the delta T's available in the HEN are more than delta T minimum.

We are seeing that while designing heat exchanger network we have to consider or we have to select a value of delta T minimum in an ad hoc fashion. Now, that ad hoc fashion delta T minimum should have some thumb rules where on the basis of which we should select it. Now, these tables gives some value of delta T minimum which are collected through experience and are valid for industrial use for oil refinery.

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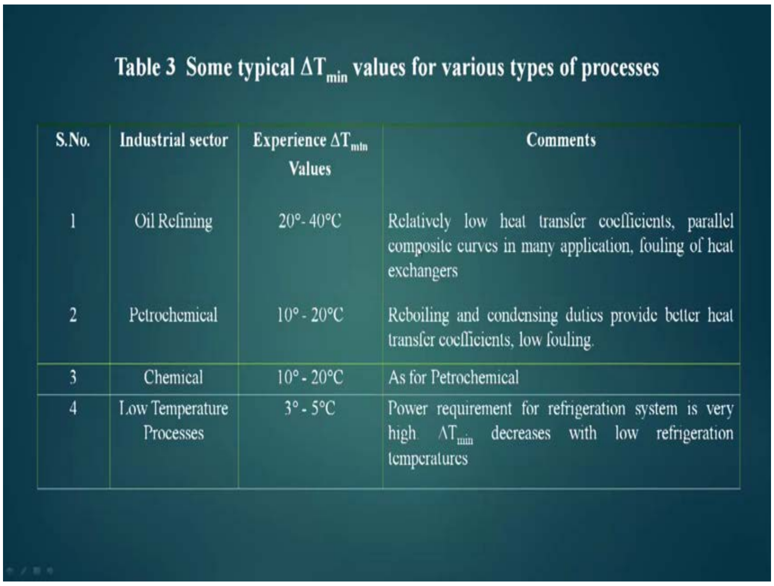

Table 3 Some typical ΔT_{min} values for various types of processes

S.No.	Industrial sector	Experience ΔT_{min} Values	Comments
1	Oil Refining	20°- 40°C	Relatively low heat transfer coefficients, parallel composite curves in many application, fouling of heat exchangers
2	Petrochemical	10° - 20°C	Reboiling and condensing duties provide better heat transfer coefficients, low fouling.
3	Chemical	10° - 20°C	As for Petrochemical
4	Low Temperature Processes	3° - 5°C	Power requirement for refrigeration system is very high. ΔT_{min} decreases with low refrigeration temperatures

This refining the delta T minimum is taking generally 20 to 40 degree centigrade relatively low heat transfer coefficients are there in the industry. In the oil refinery, parallel composite curves in many applications fouling of heat exchangers takes place and that is why a 20 to 40 degree centigrade delta T minimum is enough for petrochemicals. This delta T in a minimum taken is 10 to 20 degree centigrade because reboiling and condensing duties provide better heat transfer coefficients and low fouling.

We have seen that if the heat transfer coefficients are better we can go for lower value of delta T minimum and if they are not better or a lot of fouling is taking place then we have to go for a higher delta T minimum. For chemical industries, it is 10 to 20 degree centigrade as for petrochemicals and for low temperature processes this is 3 to 5 degree centigrade. Here, we see a departure from the ever as refrigeration cost is very high, the delta T taken for low temperature process are less why, because the power requirement that refrigeration is very high. So, delta T minimum decreases with low refrigeration temperatures.

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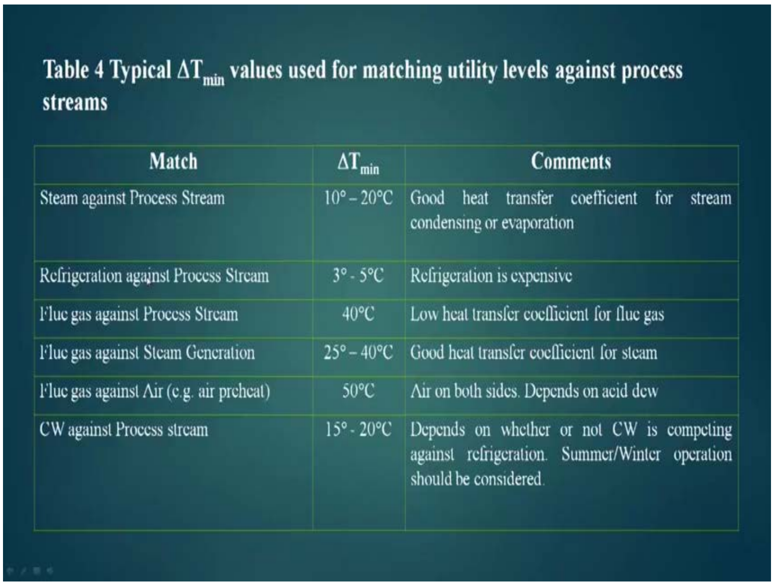

Table 4 Typical ΔT_{min} values used for matching utility levels against process streams

Match	ΔT_{min}	Comments
Steam against Process Stream	10° – 20°C	Good heat transfer coefficient for stream condensing or evaporation
Refrigeration against Process Stream	3° - 5°C	Refrigeration is expensive
Flue gas against Process Stream	40°C	Low heat transfer coefficient for flue gas
Flue gas against Steam Generation	25° – 40°C	Good heat transfer coefficient for steam
Flue gas against Air (e.g. air preheat)	50°C	Air on both sides. Depends on acid dew
CW against Process stream	15° - 20°C	Depends on whether or not CW is competing against refrigeration. Summer/Winter operation should be considered.

Now, this is based on matching, so we have steam against a process stream then delta T minimum should be taken 10 to 20 degrees centigrade, good heat transfer coefficient for steam condensing or evaporation. That is why it is 10 to 20 degrees centigrade, refrigeration against process stream 3 to 5 degrees centigrade because refrigeration is highly expensive. Flue gas against process streams, here we take 40 degree centigrade because the heat transfer coefficient for flue gas is low, flue gas against steam generation. This is 25 to 40 degrees centigrade because steam generation part will give good heat transfer coefficient, but flue gas part will give low heat transfer coefficient.

Flue gas against air, it is 50 degrees centigrade because flue gas will give you low heat transfer coefficient and, here we also give you low heat transfer coefficient. So, delta T required is high to decrease the area cold water against process stream, this is 15 to 20 degrees centigrade. It depends on whether or not cold water is competing against refrigerations, summer and winter operation should be considered because in the winter your cooling water temperature will be far less than the summer.

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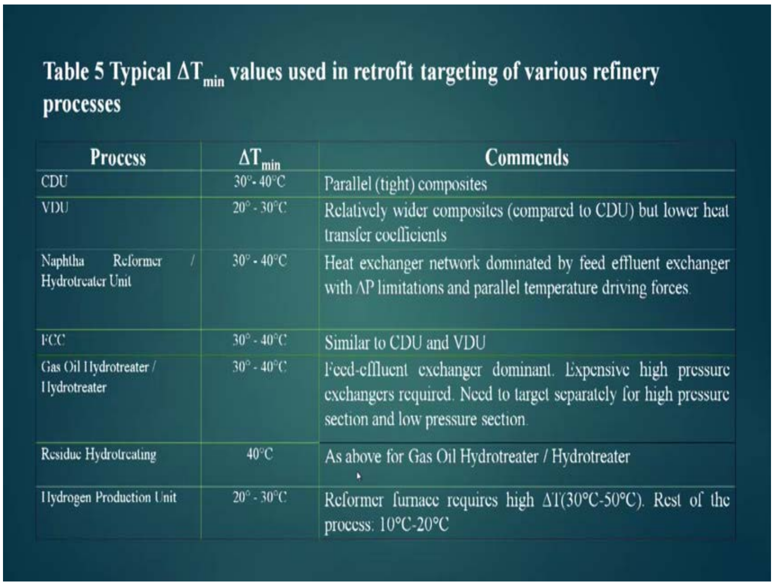

Table 5 Typical ΔT_{min} values used in retrofit targeting of various refinery processes

Process	ΔT_{min}	Commends
CDU	30°- 40°C	Parallel (tight) composites
VDU	20° - 30°C	Relatively wider composites (compared to CDU) but lower heat transfer coefficients
Naphtha Reformer / Hydrotreater Unit	30° - 40°C	Heat exchanger network dominated by feed effluent exchanger with ΔP limitations and parallel temperature driving forces.
FCC	30° - 40°C	Similar to CDU and VDU
Gas Oil Hydrotreater / Hydrotreater	30° - 40°C	Feed-effluent exchanger dominant. Expensive high pressure exchangers required. Need to target separately for high pressure section and low pressure section.
Residue Hydrotreating	40°C	As above for Gas Oil Hydrotreater / Hydrotreater
Hydrogen Production Unit	20° - 30°C	Reformer furnace requires high ΔT(30°C-50°C). Rest of the process: 10°C-20°C

Typical delta T values in the retrofit targeting of various refinery processes C D U it is 30 to 40 degrees centigrade, V D U it is 20 to 30 degrees centigrade. Naphtha reformer and hydrotreater unit it is 30 to 40 degrees centigrade, F C C this is 30 to 40 degrees centigrade gas of it hydrotreaters and hydrotreater it is 30 to 40 degrees centigrade. Residue hydrotreating, this is 40 degrees centigrade and hydrogen production unit it is 20 to 30 degrees centigrade. Now, we should try to know when a low delta T minimum value can be assigned, these are the following cases where delta T minimum considered can be taken as low.

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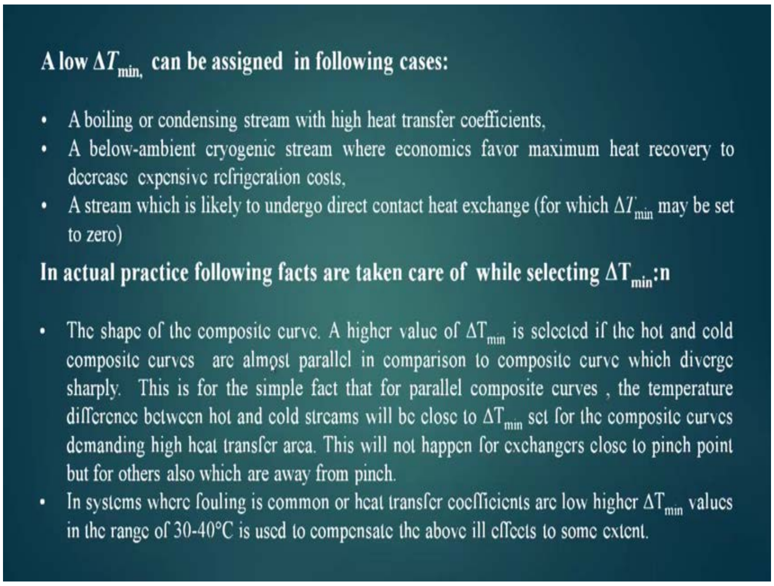

A low $\Delta T_{min,}$ can be assigned in following cases:

- A boiling or condensing stream with high heat transfer coefficients,
- A below-ambient cryogenic stream where economics favor maximum heat recovery to decrease expensive refrigeration costs,
- A stream which is likely to undergo direct contact heat exchange (for which ΔT_{min} may be set to zero)

In actual practice following facts are taken care of while selecting ΔT_{min}:n

- The shape of the composite curve. A higher value of ΔT_{min} is selected if the hot and cold composite curves are almost parallel in comparison to composite curve which diverge sharply. This is for the simple fact that for parallel composite curves , the temperature difference between hot and cold streams will be close to ΔT_{min} set for the composite curves demanding high heat transfer area. This will not happen for exchangers close to pinch point but for others also which are away from pinch.
- In systems where fouling is common or heat transfer coefficients are low higher ΔT_{min} values in the range of 30-40°C is used to compensate the above ill effects to some extent.

A boiling or condensing steam with high heat transfer coefficients we generally know that if the steam is boiling or condensing, its heat transfer coefficient is high. So, when we encounter high heat transfer coefficient, the delta T minimum can be less a below ambient cryogenic stream. Where economics favors maximum heat recovery to decrease expensive refrigeration costs, in such a scenario we can take low value of delta T minimum. This I have explained earlier also because cryogenic cost or the refrigeration cost is very lie high. So, we would lie to recover as much energy as possible, a stream which is likely to undergo direct contact heat exchange.

If direct contact heat exchange is where delta T minimum is almost 0, so in that case we can take a low delta T minimum. In actual practice, following facts are taken care of while selecting delta T minimum, the shape of composite affects a lot the value of delta T minimum. A higher value of delta T minimum is selected if the hot and cold composite curves are almost parallel in comparison to composite curves which diverge sharply. We know that, at delta T is minimum at pinch point and if delta T is minimum, the heat exchangers which are near to the pinch point have more area that means their size and large and also cost is large.

So, if two composite curves are parallel in nature that is hot and cold composite curves, it is happening as if the delta T minimum is throughout the parallel position of the curve. Thus, if you take delta T minimum to low then heat exchanger, area will increase drastically and that is why if the hot, and composite curves are parallel in nature then we can choose the delta T minimum of those curves in such a way that heat transfer area decreases.

This will not happen for exchangers close to pinch point, but for others also which are away from the pinch point. In system where fouling is common or heat transfer coefficients are low higher, delta T minimum values in the range of 30 to 40 degrees centigrade is taken and it compensates the ill effect of to some extent.

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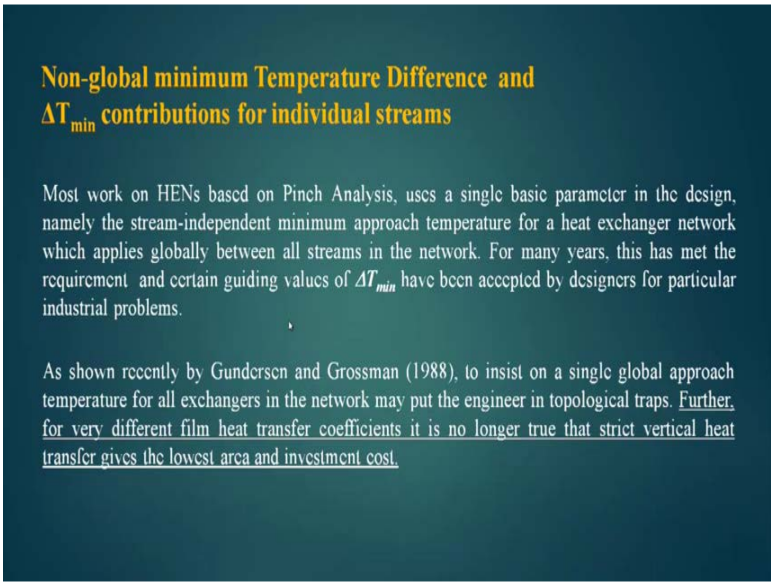

Non-global minimum Temperature Difference and ΔT_{min} contributions for individual streams

Most work on HENs based on Pinch Analysis, uses a single basic parameter in the design, namely the stream-independent minimum approach temperature for a heat exchanger network which applies globally between all streams in the network. For many years, this has met the requirement and certain guiding values of ΔT_{min} have been accepted by designers for particular industrial problems.

As shown recently by Gundersen and Grossman (1988), to insist on a single global approach temperature for all exchangers in the network may put the engineer in topological traps. Further, for very different film heat transfer coefficients it is no longer true that strict vertical heat transfer gives the lowest area and investment cost.

Now, let us see a different aspect of delta T minimum, up till now whatever we have learnt was a global delta T minimum. Now, we think or we will discuss if there can be a concept of non global minimum temperature difference and delta T minimum contribution for individual streams. Most work of HENs are based on pinch analysis, it uses a single basic parameter in the design namely the stream independent minimum approach temperature for a heat exchanger network which applies globally between all streams in the network. That is why we say that pinch analysis uses global delta T minimum concept, but this concept has been challenged by many and they have found out the draw backs of this system.

For many years, this met the requirement of certain guiding values of delta T minimum have been accepted by the designers for particular industrial problems. As shown recently by Gunderson and Grossman in 1988 to insist on a single global approach temperature for all heat exchangers in the network may put the engineer in topological trap.

This we will see, further for very different film heat transfer coefficients, it is also no longer true that strict vertical heat transfer gives the lowest area and investment cost. We have seen that if the heat transfer coefficients of the different streams in a HEN differ by an order of magnitude, then by considering vertical heat transfer. As in the case of Barth algorithm we will not provide minimum area, only the non vertical heat transfer will provide minimum area in this case.

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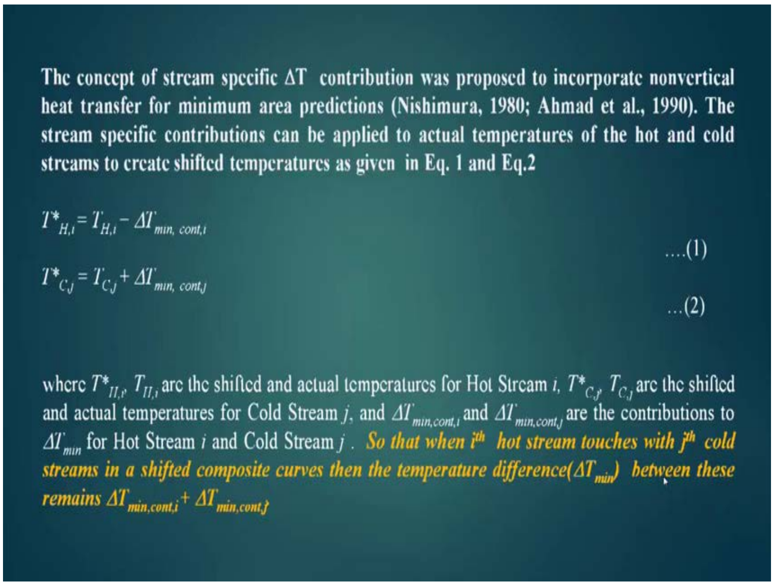

The concept of stream specific ΔT contribution was proposed to incorporate nonvertical heat transfer for minimum area predictions (Nishimura, 1980; Ahmad et al., 1990). The stream specific contributions can be applied to actual temperatures of the hot and cold streams to create shifted temperatures as given in Eq. 1 and Eq.2

$$T^*_{H,i} = T_{H,i} - \Delta T_{min,\ cont,i} \quad \text{....(1)}$$

$$T^*_{C,j} = T_{C,j} + \Delta T_{min,\ cont,j} \quad \text{...(2)}$$

where $T^*_{H,i}$, $T_{H,i}$ are the shifted and actual temperatures for Hot Stream i, $T^*_{C,j}$, $T_{C,j}$ are the shifted and actual temperatures for Cold Stream j, and $\Delta T_{min,cont,i}$ and $\Delta T_{min,cont,j}$ are the contributions to ΔT_{min} for Hot Stream i and Cold Stream j. *So that when i^{th} hot stream touches with j^{th} cold streams in a shifted composite curves then the temperature difference(ΔT_{min}) between these remains $\Delta T_{min,cont,i} + \Delta T_{min,cont,j}$*

Now, the concept of stream specific delta T contribution was proposed to incorporate non vertical heat transfer for minimum area prediction Nishimura in 1980, Ahmad et al in 1990 proposed this. The stream specific contributions can be applied to actual temperatures of the hot and cold streams to create shifted temperatures as given in equation 1 and equation 2. The equation 1 tells that T star H i which is the shifted temperature when we are representing the shifted temperature by putting a star or asterisks is equal to T H i.

Actual temperature of this stream minus delta T minimum contribution which is specific to the i-th stream or i-th hot stream. Similarly, T star C j that means shifted temperature of the cold stream j plus is equal to actual temperature of the cold streams C T, C j plus delta T minimum contribution of that cold stream j. Where the T star H i and T H i are the shifted, actual temperature T shifted temperature or actual temperature of the hot stream similarly, T star C j is a shifted temperature of the cold stream and T C j is the actual temperature of the cold stream and delta T minimum. Contribution high is the delta T contribution for the hot stream and delta T minimum contribution j is the delta T minimum contribution for the cold stream.

So, that when i hot stream touches the j-th cold stream in a shifted composite curve then the temperature difference delta T minimum is between these remains is delta T minimum. Contribution i plus delta T minimum contribution of j means the temperature difference between the two streams shifted streams will delta T minimum contribution of i plus delta T minimum contribution of j.

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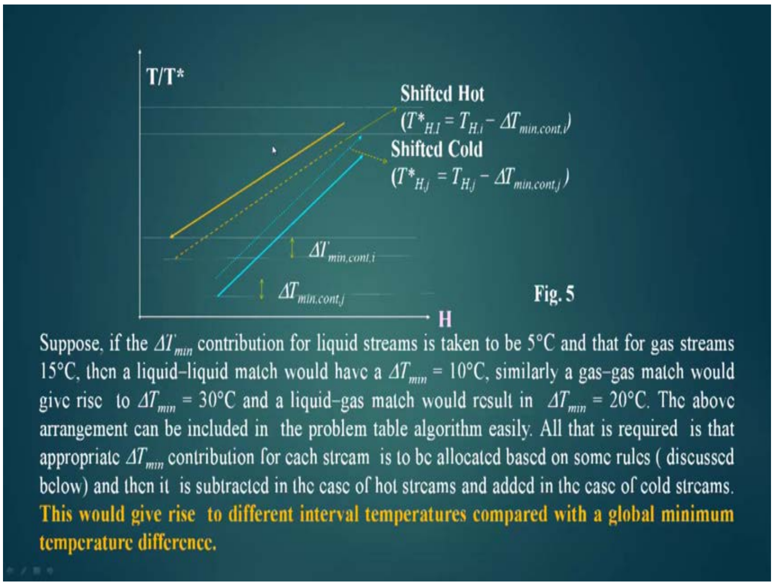

Fig. 5

Suppose, if the ΔT_{min} contribution for liquid streams is taken to be 5°C and that for gas streams 15°C, then a liquid–liquid match would have a ΔT_{min} = 10°C, similarly a gas–gas match would give rise to ΔT_{min} = 30°C and a liquid–gas match would result in ΔT_{min} = 20°C. The above arrangement can be included in the problem table algorithm easily. All that is required is that appropriate ΔT_{min} contribution for each stream is to be allocated based on some rules (discussed below) and then it is subtracted in the case of hot streams and added in the case of cold streams. **This would give rise to different interval temperatures compared with a global minimum temperature difference.**

Now, this show in a figure how the shifting will take place this is the hot stream. Now, it is vertically shifted to this stage and this shifting is delta T minimum contribution i. This is cold stream shifted upward by an amount delta T minimum, contribution j and this is how we compute the shifted temperatures in a case when contribution for each stream is added.

Now, let us explain it with an example suppose if the delta T minimum contribution for liquid streams is taken to be 5 degree centigrade and that for a gas streams is taken to be 15 degree centigrade. Then the liquid match would have a delta T minimum of 10 degree centigrade, similarly a gas match would have a delta T minimum of 30 degree centigrade.

A liquid gas stream match will be delta T minimum 20 degree centigrade the above arrangement can be included in the problem table algorithm. Easily, all that is required is that, the appropriate delta T minimum contribution for each stream is to be allocated based on some rules. What will be that rule we will discuss later on, so this would give rise to different interval temperatures. Compared to the global minimum temperature difference we will see that if such type of contributions are included, then how the problem differs from a case when globally delta T minimum is taken.

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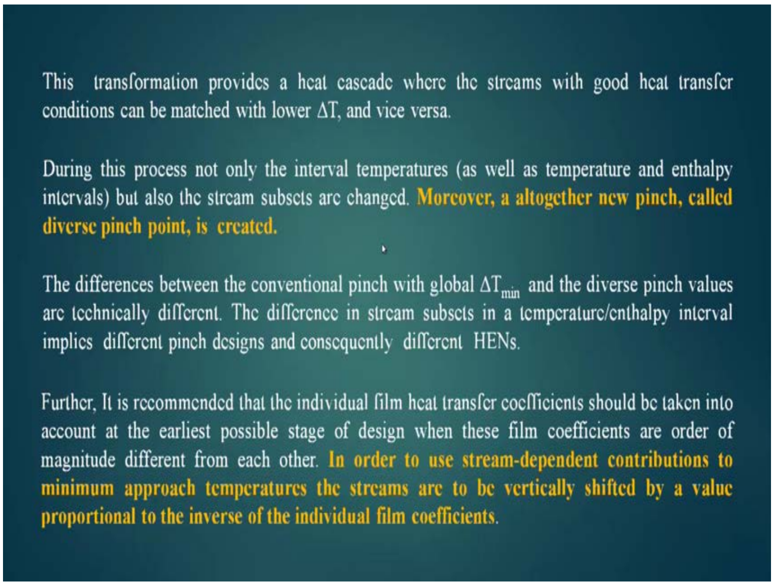

This transformation provides a heat cascade where the streams with good heat transfer conditions can be matched with lower ΔT, and vice versa.

During this process not only the interval temperatures (as well as temperature and enthalpy intervals) but also the stream subsets are changed. **Moreover, a altogether new pinch, called diverse pinch point, is created.**

The differences between the conventional pinch with global ΔT_{min} and the diverse pinch values are technically different. The difference in stream subsets in a temperature/enthalpy interval implies different pinch designs and consequently different HENs.

Further, It is recommended that the individual film heat transfer coefficients should be taken into account at the earliest possible stage of design when these film coefficients are order of magnitude different from each other. **In order to use stream-dependent contributions to minimum approach temperatures the streams are to be vertically shifted by a value proportional to the inverse of the individual film coefficients.**

This transformation provides a heat cascade where streams with good heat transfer coefficients can be matched with lower delta T and vice versa. This is what we are needing, because if the stream has got a lowery transfer coefficient, so the delta T minimum or delta T taken should be taken higher. So, that area will be less and if the heat transfer coefficients of the streams are higher than the lower delta T minimum or lower delta T will do the purpose.

During the process, not only the interval temperatures as well as temperatures and enthalpy intervals, but also the stream subsets are changed. When we take individual contributions, then the temperature levels will change, enthalpy intervals will change and the stream population in a enthalpy interval will also change.

Moreover, altogether new pinch which will be called diverse pinch point is created, the differences between the conventional pinch with global delta T minimum and the diverse pinch values are technically different. The difference in stream subsets in a temperature enthalpy interval implies different pinch diagram and consequently different HENs. So, we can expect that the HEN which will be designed based on the global temperature minimum will be different than the HEN which will be designed by using the delta T minimum contribution of the different streams.

Further, it is recommended that the individual film heat transfer coefficients should be taken into account at the earliest possible stage of design when these film coefficients are order of the magnitude different than each other. That means when order of the magnitude will be high between the film heat transfer coefficients, then the contribution or individual contributions of the streams will be useful for us. In order to use stream dependent contributions to minimum approach temperatures, the streams are to be vertically shifted by a value proportional to the inverse of the individual film coefficients. This gives a rule how to find out the stream dependent contribution, let us see in detail.

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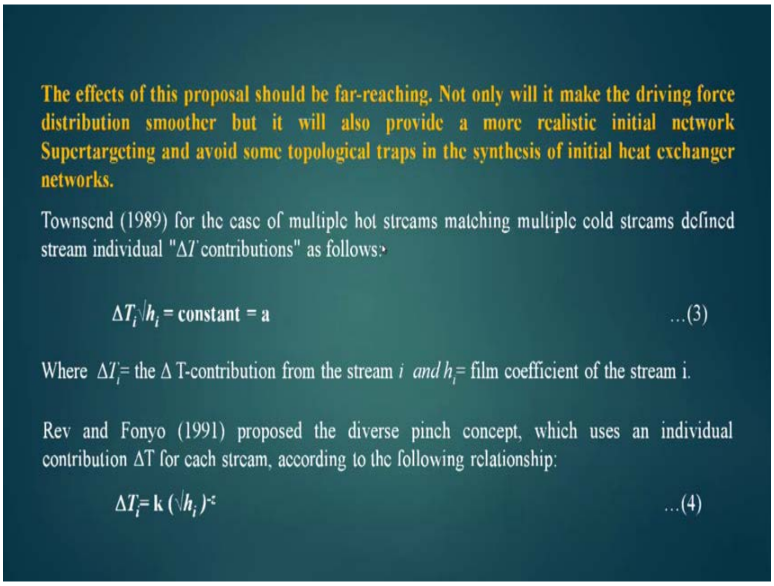

The effects of this proposal should be far-reaching. Not only will it make the driving force distribution smoother but it will also provide a more realistic initial network Supertargeting and avoid some topological traps in the synthesis of initial heat exchanger networks.

Townsend (1989) for the case of multiple hot streams matching multiple cold streams defined stream individual "ΔT contributions" as follows:

$$\Delta T_i \sqrt{h_i} = \text{constant} = a \qquad \ldots(3)$$

Where ΔT_i = the Δ T-contribution from the stream i and h_i = film coefficient of the stream i.

Rev and Fonyo (1991) proposed the diverse pinch concept, which uses an individual contribution ΔT for each stream, according to the following relationship:

$$\Delta T_i = k\,(\sqrt{h_i})^{-\varepsilon} \qquad \ldots(4)$$

The effects of this proposal should be far reaching not only will it make the driving force distribution smoother. But, it will also provide a more realistic initial network, super targeting and avoid some topological traps in the synthesis of initial heat exchanger, so two benefits I get out of it if I get a stream based contribution.

The first is that it if the driving force distribution throughout the HEN is smoother and this is one of the key points of efficiency of a HEN. If the distribution is not proper, then I cannot expect to get a optimum HEN, the second thing is that I get a initial network which is free from topological trap. Now, let us see that what should be the rule for find out the stream contributions town send in 1989.

For the case of multiple hot streams, matching multiple cold streams defined stream individual delta T contributions as follow, so delta T i into root over h i is equal to constant a. We get this root where delta T i is the delta T contribution for the stream i and h i is the film coefficient of the stream i. Rev and Fonyo in 1991 proposed the diverse pinch concept which uses an individual contribution Delta T for each stream.

According to the following relationship delta T I, that is the contribution for i-th stream is equal to k root over h to the power minus z. Now, this relationship appears to be correct because when h will be less, delta T i that is the contribution of delta T minimum for i-th stream will increase and when h will be more it will decrease.

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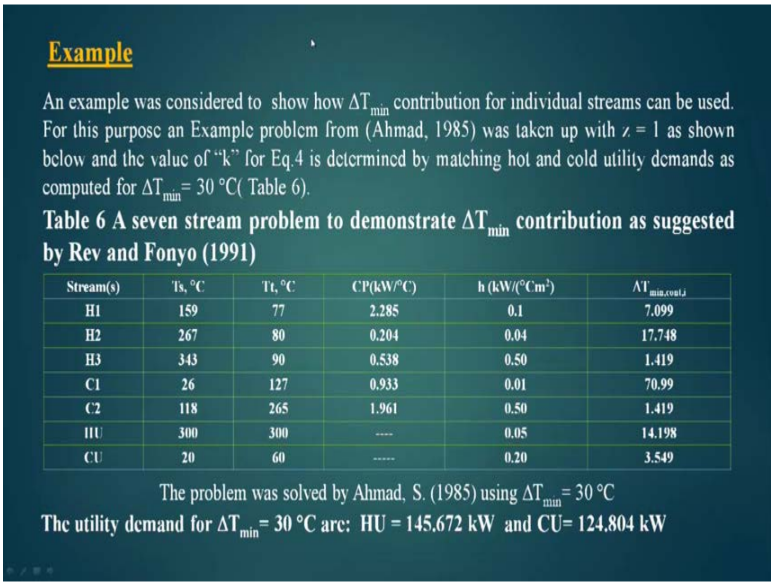

Example

An example was considered to show how ΔT_{min} contribution for individual streams can be used. For this purpose an Example problem from (Ahmad, 1985) was taken up with $z = 1$ as shown below and the value of "k" for Eq.4 is determined by matching hot and cold utility demands as computed for $\Delta T_{min} = 30$ °C(Table 6).

Table 6 A seven stream problem to demonstrate ΔT_{min} contribution as suggested by Rev and Fonyo (1991)

Stream(s)	Ts, °C	Tt, °C	CP(kW/°C)	h (kW/(°Cm^2))	$\Delta T_{min,cont,i}$
H1	159	77	2.285	0.1	7.099
H2	267	80	0.204	0.04	17.748
H3	343	90	0.538	0.50	1.419
C1	26	127	0.933	0.01	70.99
C2	118	265	1.961	0.50	1.419
HU	300	300	----	0.05	14.198
CU	20	60	-----	0.20	3.549

The problem was solved by Ahmad, S. (1985) using $\Delta T_{min} = 30$ °C

The utility demand for $\Delta T_{min} = 30$ °C are: HU = 145.672 kW and CU= 124.804 kW

Let us take an example and see how this concept can be utilized and what is the benefit of this concept. An example was considered to show how delta T minimum contribution for individual streams can be used for this purpose. An example of problem from Ahmad 1985 was taken up with z equal to 1 as shown below and the value of k for equation 4 is determined by matching hot and cold utility demands.

As computed for delta T minimum equal to 30 degree, now this is a seven stream problem which has been taken to demonstrate delta T minimum contribution as suggested by Rev and Fonyo in 1991. Here, we have taken delta T minimum equal to 30 degree, H U is that hot utility is 145.672 kilo Watt and cold utility is 124.804 kilo Watt.

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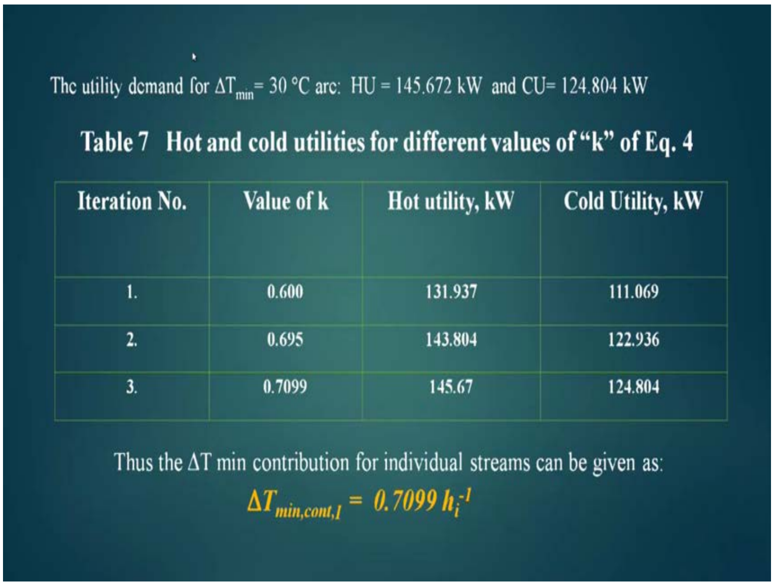

The utility demand for ΔT_{min} = 30 °C are: HU = 145.672 kW and CU= 124.804 kW

Table 7 Hot and cold utilities for different values of "k" of Eq. 4

Iteration No.	Value of k	Hot utility, kW	Cold Utility, kW
1.	0.600	131.937	111.069
2.	0.695	143.804	122.936
3.	0.7099	145.67	124.804

Thus the ΔT min contribution for individual streams can be given as:

$$\Delta T_{min,cont,I} = 0.7099\, h_i^{-1}$$

Now, the hot utility amount and cold utility amount is known, so what we will do we will find out the delta T contributions based on the equations. For different value of k we will do it, so when the value of k is taken 0.6 the hot utility requirement of the problem becomes 131.937 and cold utility 111.067. But, when we take the k value to be 0.7099 then we see that the hot utility requirement and cold utility requirement matches. So, if I take delta T minimum contribution as per the equation shown below that is 0.7099 into h i to the power minus 1 then i can compute the rest part of my problem.

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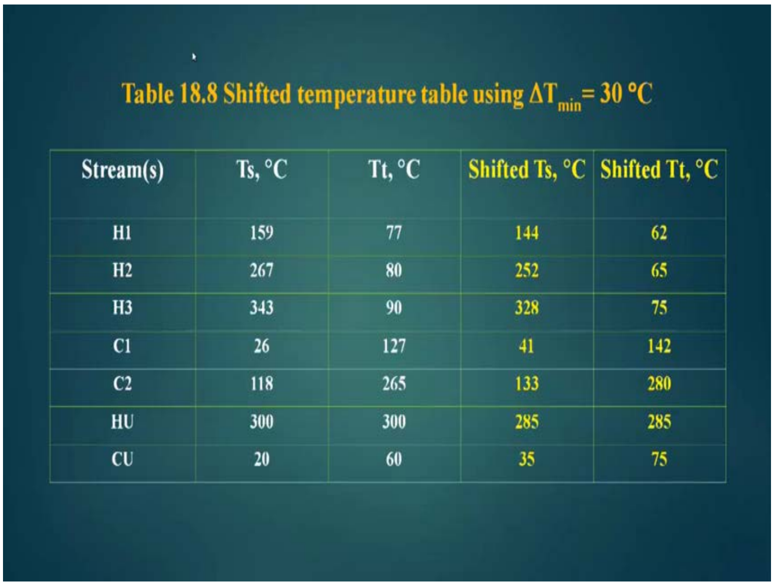

Table 18.8 Shifted temperature table using $\Delta T_{min} = 30$ °C

Stream(s)	Ts, °C	Tt, °C	Shifted Ts, °C	Shifted Tt, °C
H1	159	77	144	62
H2	267	80	252	65
H3	343	90	328	75
C1	26	127	41	142
C2	118	265	133	280
HU	300	300	285	285
CU	20	60	35	75

So, here the table shows the shifted temperature using delta T minimum is equal to 30 degree centigrade. Now, T s, T t is being calculated and using the contribution based on the streams the shifted T s and shifted T t is computed as shown in these two columns.

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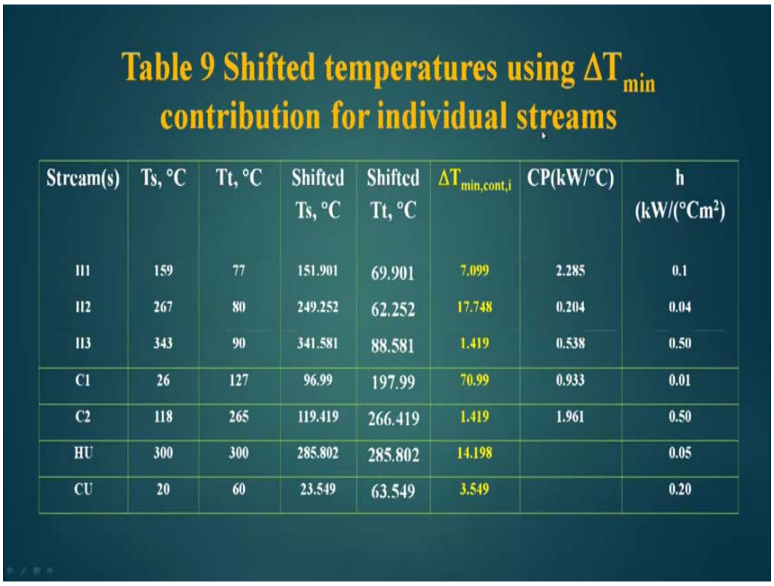

Table 9 Shifted temperatures using ΔT_{min} contribution for individual streams

Stream(s)	Ts, °C	Tt, °C	Shifted Ts, °C	Shifted Tt, °C	$\Delta T_{min,cont,i}$	CP(kW/°C)	h (kW/(°Cm^2))
H1	159	77	151.901	69.901	7.099	2.285	0.1
H2	267	80	249.252	62.252	17.748	0.204	0.04
H3	343	90	341.581	88.581	1.419	0.538	0.50
C1	26	127	96.99	197.99	70.99	0.933	0.01
C2	118	265	119.419	266.419	1.419	1.961	0.50
HU	300	300	285.802	285.802	14.198		0.05
CU	20	60	23.549	63.549	3.549		0.20

The shifted temperatures using delta T minimum contribution for individual streams this is the shifted temperatures, these are the actual temperatures. This is the delta T minimum contribution for different streams, for h 1 this is 7.099, for h 2 it is 17.748 and so on. So, far and where we will see here that the if the heat transfer coefficient of the stream is less, the contribution is more and if the heat transfer coefficient of stream is more the contribution is less. These are the C P values and this is the h value you see, here the h is 0.1 the contribution is 7.099 when h decreases 10 times about 0.04 the contribution increases.

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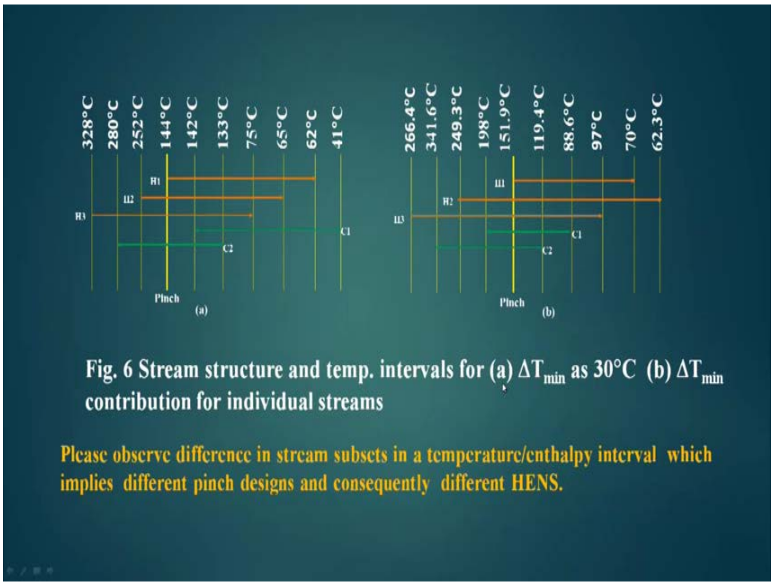

Fig. 6 Stream structure and temp. intervals for (a) ΔT_{min} as 30°C (b) ΔT_{min} contribution for individual streams

Please observe difference in stream subsets in a temperature/enthalpy interval which implies different pinch designs and consequently different HENS.

Now, if you see the different temperatures, the temperature intervals we find the temperature intervals on here and temperature intervals on here are different. This part is a global delta T m 30 degree taken and, here for this part delta T minimum contribution for individual streams are taken. Then also we see that the streams start from different temperature level to different temperature level, if you see here h 3 starts from 328 degree centigrade to 75 degree centigrade.

Here, h 3 starts from 266.4 degree centigrade to 97 degree centigrade, further we see that if you see the third interval or fourth interval of fifth interval the numbers of streams are different. So, here we find that as here you see this even starts from here to here, but how will it even start from here to here.

So, here we have three streams and if we consider here we have two streams, here we have one stream, and here we have two streams. So, the stream contribution in a particular temperature interval also changes, so please observe the difference in streams subsets. In a temperature enthalpy interval which implies different pinch designs and consequently different HENs, so if I design a HEN based on this it will be different.

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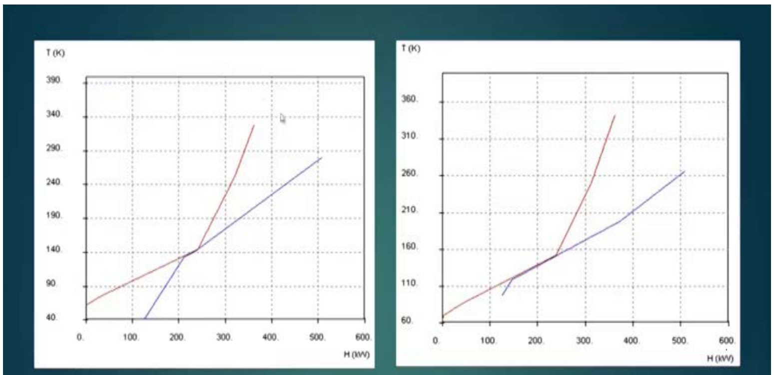

(a) (b)

Fig.7 (a) Shifted composite curve taking ΔT_{min} as 30°C (b) Shifted composite curve taking ΔT_{min} contribution for individual streams

Now, if I plot the hot and cold composite curve from my global delta T minimum which is 30 degree this looks like this. If for the delta T minimum contribution of individual streams this looks like this, so there is a lot difference between these two plots.

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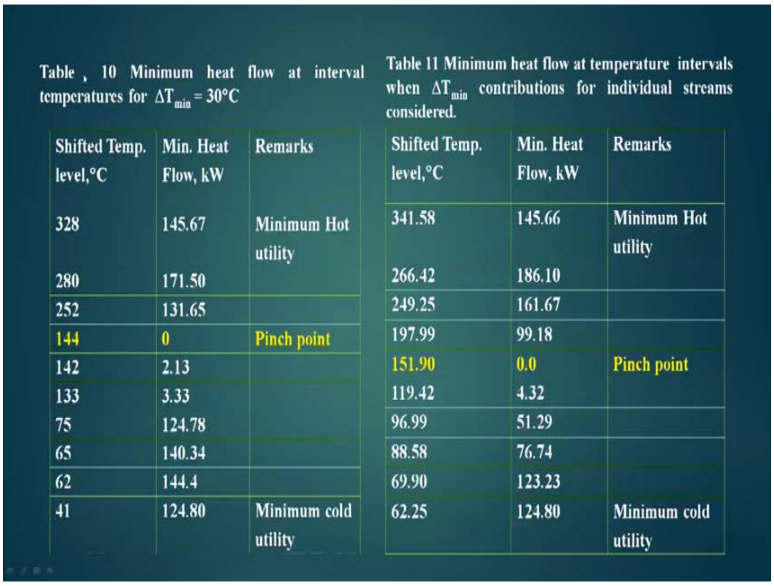

Table , 10 Minimum heat flow at interval temperatures for $\Delta T_{min} = 30°C$

Shifted Temp. level,°C	Min. Heat Flow, kW	Remarks
328	145.67	Minimum Hot utility
280	171.50	
252	131.65	
144	0	Pinch point
142	2.13	
133	3.33	
75	124.78	
65	140.34	
62	144.4	
41	124.80	Minimum cold utility

Table 11 Minimum heat flow at temperature intervals when ΔT_{min} contributions for individual streams considered.

Shifted Temp. level,°C	Min. Heat Flow, kW	Remarks
341.58	145.66	Minimum Hot utility
266.42	186.10	
249.25	161.67	
197.99	99.18	
151.90	0.0	Pinch point
119.42	4.32	
96.99	51.29	
88.58	76.74	
69.90	123.23	
62.25	124.80	Minimum cold utility

Now, this shows minimum heat flow at interval temperatures for delta T minimum and global delta T minimum is taken. You find that minimum heat flow also changes in comparison to this though minimum hot utility requirement, and minimum cold utility requirements are the same for both foul less. But, internal heat flow changes the pinch is, here is 144 the pinch point, here is 151.90. So, pinch point also changes for both the problems.

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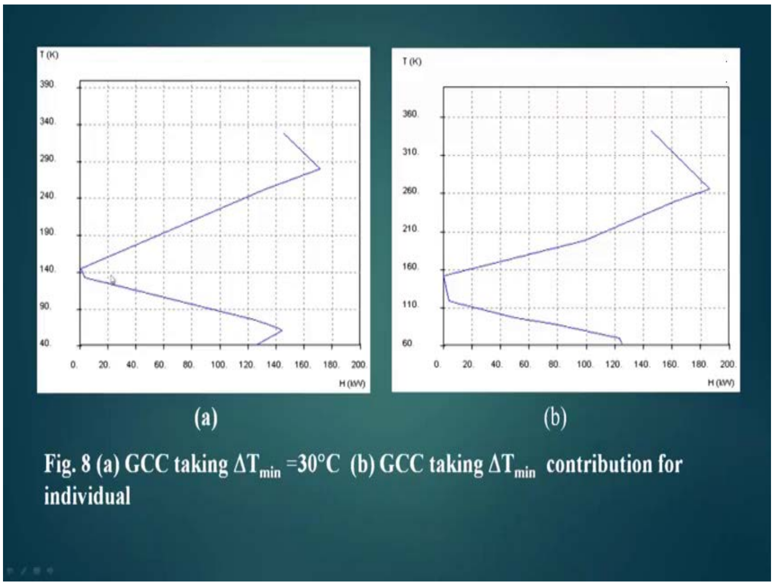

(a) (b)

Fig. 8 (a) GCC taking ΔT_{min} =30°C (b) GCC taking ΔT_{min} contribution for individual

Now, my G C C for global delta T minimum equal to 30 degree looks like this and the second pass shows for delta T minimum contribution for individual this two also changes.

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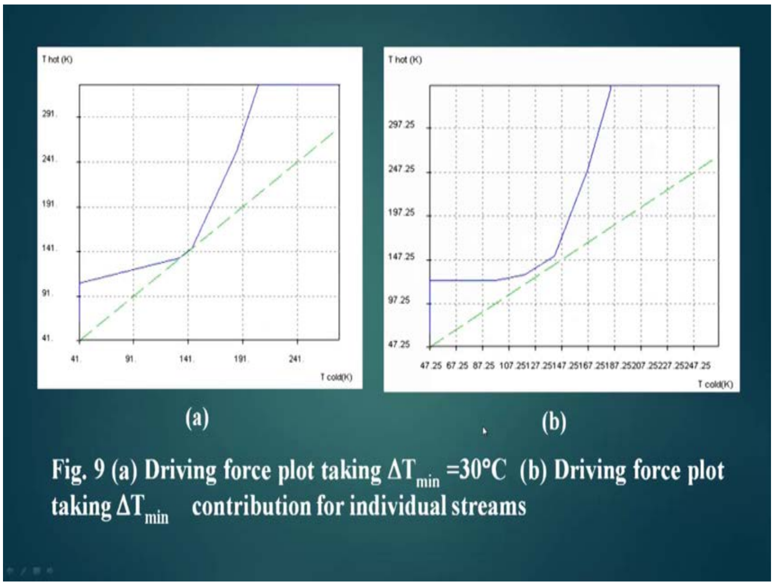

(a) (b)

Fig. 9 (a) Driving force plot taking ΔT_{min} =30°C (b) Driving force plot taking ΔT_{min} contribution for individual streams

A lot this is the driving force plot, for global delta T minimum equal to 30 degree centigrade. Where the delta T minimum contribution for individual streams are taken up, what is the conclusion, the conclusion is that from figure 6 and 9 and table 8 and 10, it is clear.

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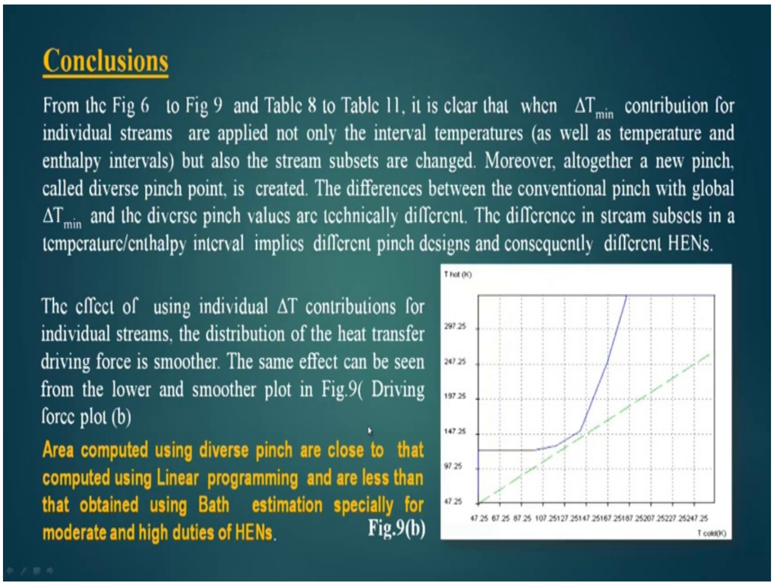

Conclusions

From the Fig 6 to Fig 9 and Table 8 to Table 11, it is clear that when ΔT_{min} contribution for individual streams are applied not only the interval temperatures (as well as temperature and enthalpy intervals) but also the stream subsets are changed. Moreover, altogether a new pinch, called diverse pinch point, is created. The differences between the conventional pinch with global ΔT_{min} and the diverse pinch values are technically different. The difference in stream subsets in a temperature/enthalpy interval implies different pinch designs and consequently different HENs.

The effect of using individual ΔT contributions for individual streams, the distribution of the heat transfer driving force is smoother. The same effect can be seen from the lower and smoother plot in Fig.9(Driving force plot (b)

Area computed using diverse pinch are close to that computed using Linear programming and are less than that obtained using Bath estimation specially for moderate and high duties of HENs.

Fig.9(b)

That when delta T minimum contribution for individual streams are applied, not only the interval temperatures as well as the temperatures and enthalpy intervals, but also the stream subsets are changed that we have seen. Moreover, altogether a new pinch called diverse pinch point is created, the differences between the conventional pinch with global delta T minimum and the diverse pinch values are technically different. This we have also observed the difference in stream subsets in a temperature or enthalpy interval implies different pinch designs and consequently different HENs.

So, it proves that in both the methods different HENs will be created and they will not be alike the effect of using individual delta T contributions. For individual streams, the distribution of the heat transfer driving force is smoother when we take delta T minimum contribution, my distribution of driving force is better than the earlier one. When global delta T minimum is considered, the same effect can be seen from the lower smoother plot.

In figure 9, this shows that it is smoother delta, the driving force is smoother the last point is very important. Area computed using diverse pinch are close to that computed using linear programming and are less than that obtained. Using the Bath estimation, especially for moderate and high duties of the hen, so that if we are going for delta T minimum contribution. For each individual streams than the area computed will be less than if it is computed using Bath and Dorsum which is its particular heat transfer and global delta T minimum. It is almost equal to the linear programming result which does not consider vertical heat transfer. So, if the heat transfers coefficients are differing, then it is better to use delta T minimum contribution for individual streams because we will get less area of the HEN if we design it using this condition.

Thank you.