CHE526: PINCH TECHNOLOGY

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Steps of Pinch Analysis

1. **Identification of the Hot, Cold and Utility Streams in the Process**
    - 'Hot Streams' are those that must be cooled or are available to be cooled. e.g. product cooling before storage
    - 'Cold Streams' are those that must be heated e.g. feed preheat before a reactor.
    - 'Utility Streams' are used to heat or cool process streams, when heat exchange between process streams is not practical or economic, e.g. hot utilities (steam, hot water, flue gas, etc.) and cold utilities (cooling water, air, refrigerant, etc.).
    - care must be taken of stream that is not available for heat exchange, despite undergoing changes in temperature, e.g. when a gas stream is compressed the stream temperature rises due to the conversion of mechanical energy into heat and not by fluid to fluid heat exchange.
2. **Thermal Data Extraction for Process & Utility Streams**
    - For each hot, cold and utility stream identified, the following thermal data is extracted from the process material and heat balance flow sheet:

PINCH ANALYSIS

- Supply temperature (T_S): the temperature at which the stream is available.
- Target temperature (T_T): the temperature the stream must be taken to.
- Heat capacity flow rate (CP): the product of flow rate (m) in kg/sec and specific heat (C_P, kJ/kg^{0}C). $CP = m \times C_P$
- Enthalpy Change (ΔH) associated with a stream passing through the exchanger is given by the First Law of Thermodynamics: $\Delta H = Q \pm W$
- In a heat exchanger, no mechanical work is being performed: $W = 0$
- The above equation simplifies to: $\Delta H = Q$, where Q represents the heat supply or demand associated with the stream. It is given by the relationship: $Q = CP \times (T_S - T_T)$.
- Enthalpy Change, $H = CP \times (T_S - T_T)$

A TYPICAL STREAM DATA

Stream No.	Stream Name	Supply Temp., ^{0}C	Taregt Temp, ^{0}C	Heat Cap. Flow, kJ/kg^{0}C	Enthalpy change, kW
1	Feed	60	205	20	2900
2	Reactor out	270	160	18	1980
3	Product	220	70	35	5250
4	Recycle	160	210	50	2500

3. Selection of Initial ΔT_{min} value

- A minimum allowable temperature difference ΔT_{min} must be specified which prohibits any temperature crossover between the hot and the cold stream
- the temperature of the hot and cold streams at any point in the exchanger must always have a minimum temperature difference (ΔT_{min}).
- i.e. Hot stream Temp. $T_H - T_C = \Delta T_{min}$
- This ΔT_{min} value represents the bottleneck in the heat recovery.
- The value of ΔT_{min} is determined by the overall heat transfer coefficients (U) and the geometry of the heat exchanger.
- In a network design, the type of heat exchanger to be used at the pinch will determine the practical ΔT_{min} for the network. For example, an initial selection for the ΔT_{min} value for shell and tubes may be 3-5^{0}C (at best) while compact exchangers such as plate and frame often allow for an initial selection of 2-3^{0}C.

$$Q = UA\,\Delta T$$

$$\Delta T_{lm} = \frac{(T_{Hin} - T_{Cout}) - (T_{Hout} - T_{Cin})}{\ln \dfrac{(T_{Hin} - T_{Cout})}{(T_{Hout} - T_{Cin})}}$$

HHB

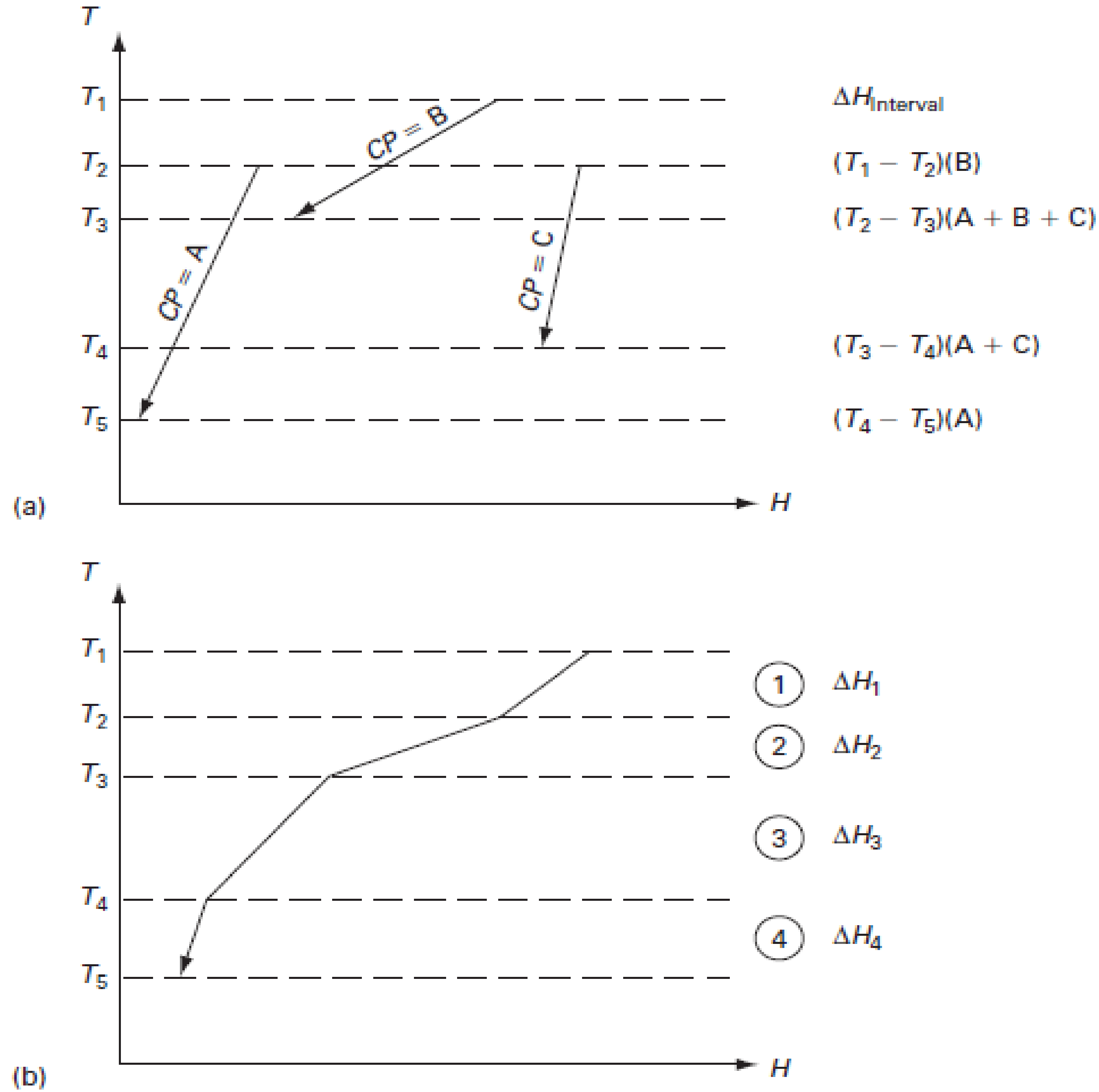
Typical ΔT_{min} values for various types of process

No	Industrial Sector	ΔT_{min}
1	Oil Refining	20-40ºC
2	Petrochemical	10-20ºC
3	Chemical	10-20ºC
4	Low Temperature Processes	3-5ºC

- For a given value of heat transfer load (Q), if smaller values of ΔT_{min} are chosen, the area requirements rise. If a higher value of ΔT_{min} is selected the heat recovery in the exchanger decreases and demand for external utilities increases.
- Thus, the selection of ΔT_{min} value has implications for both capital and energy costs.

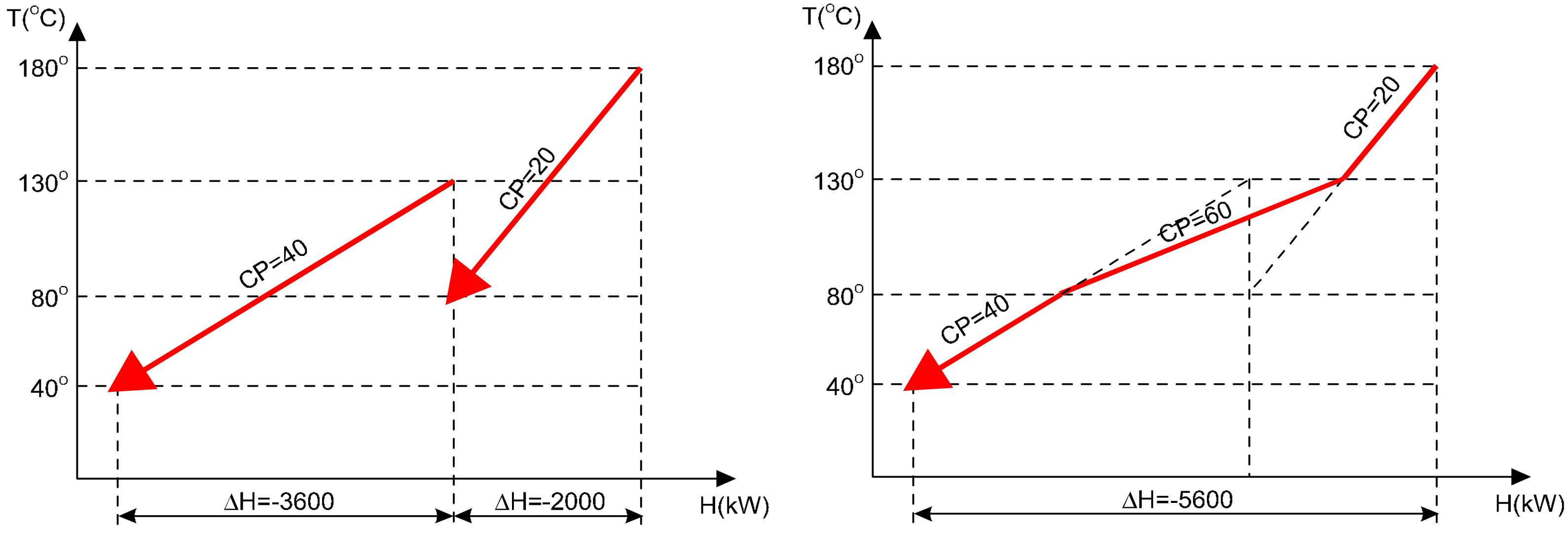
4. Construction of Composite Curves and Grand Composite Curve

- 'Composite curves' is used to set energy targets ahead of design.
- It consist of temperature (T)–enthalpy (H) profiles of heat availability in the process (the hot composite curve) and heat demands in the process (the cold composite curve) together in a graphical representation.
- Stream with constant heat capacity (CP) value is represented on a T – H diagram by a straight line running from stream T_S to stream T_T.
- When there are a number of hot and cold streams, the construction of hot and cold composite curves simply involves the addition of the enthalpy changes of the streams in the respective temperature intervals.
- A complete hot or cold composite curve consists of a series of connected straight lines, each change in slope represents a change in overall hot stream heat capacity flow rate (CP).


T
T1
T2
T3
T4
T5
CP = B
CP = A
CP = C
ΔH Interval
(T1 − T2)(B)
(T2 − T3)(A + B + C)
(T3 − T4)(A + C)
(T4 − T5)(A)
H
(a)
T
T1
T2
T3
T4
T5
1
2
3
4
ΔH1
ΔH2
ΔH3
ΔH4
H
(b)

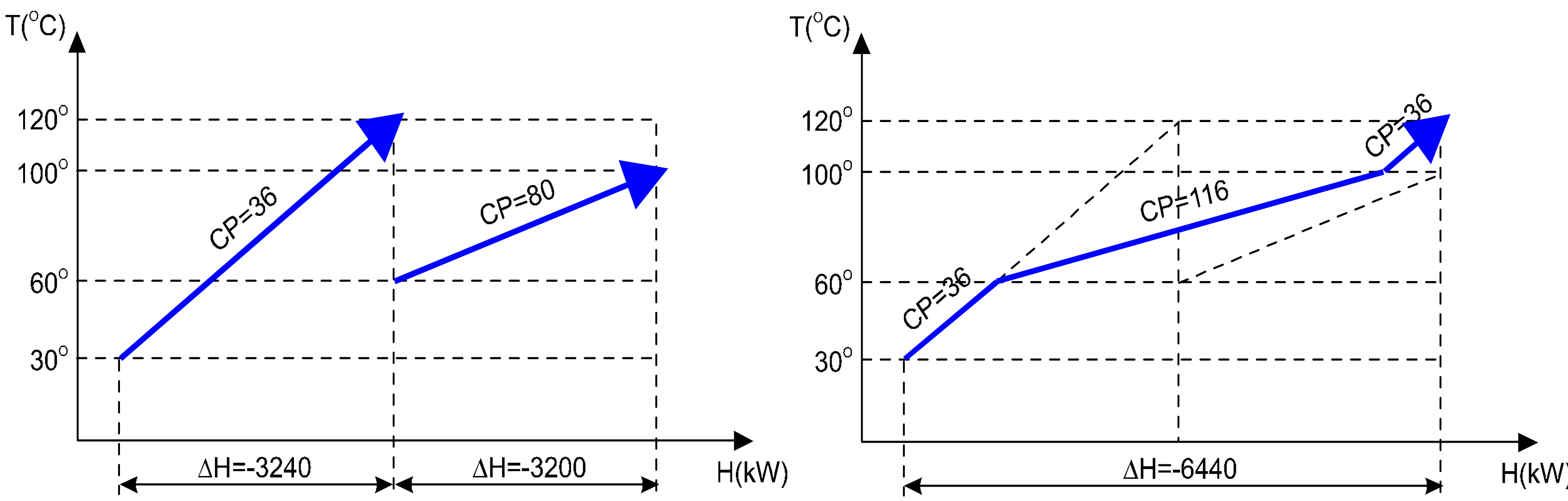
2. Composite Curve

- Hot composite curve



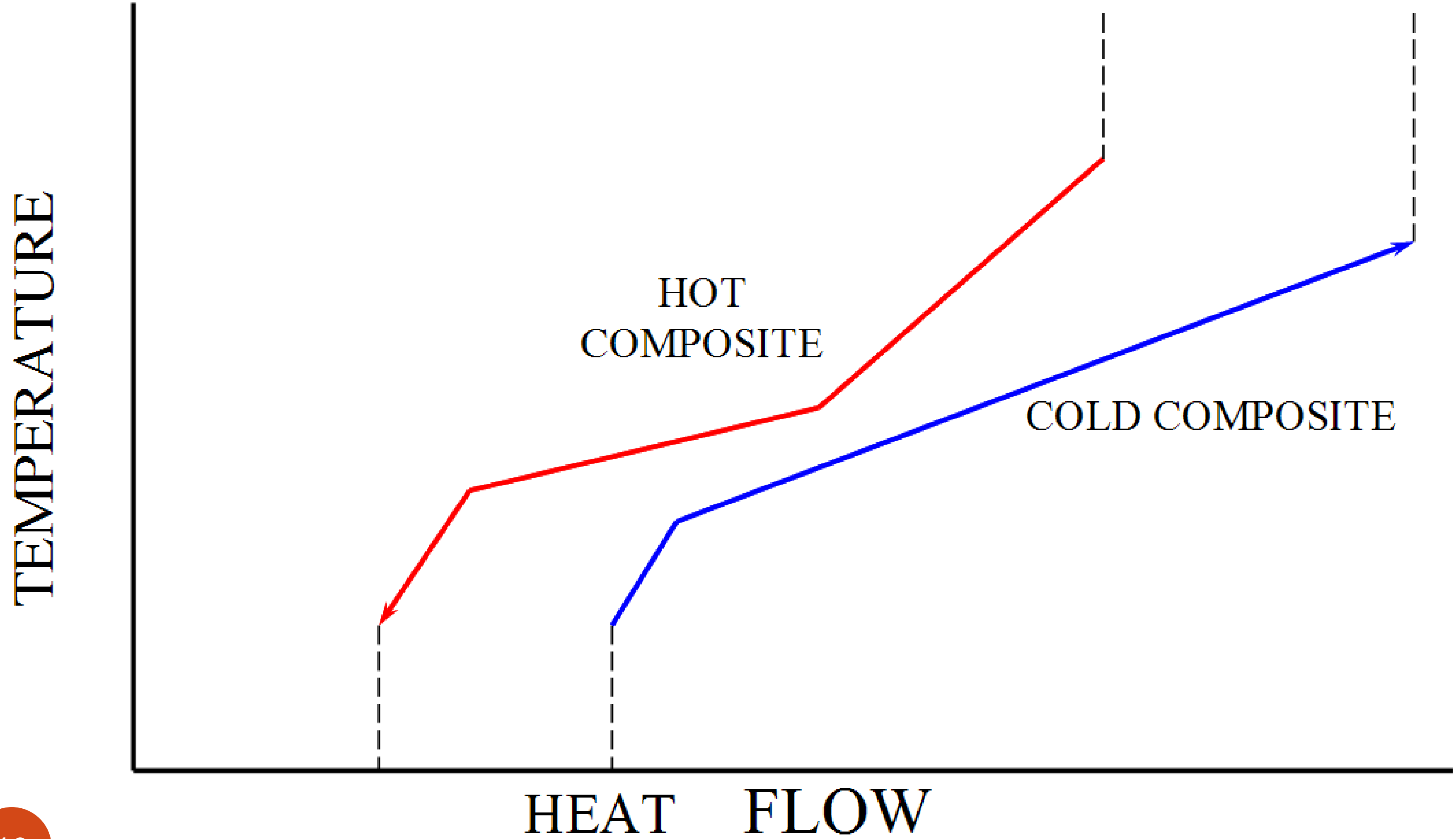
Composite Curve

- Cold composite curve

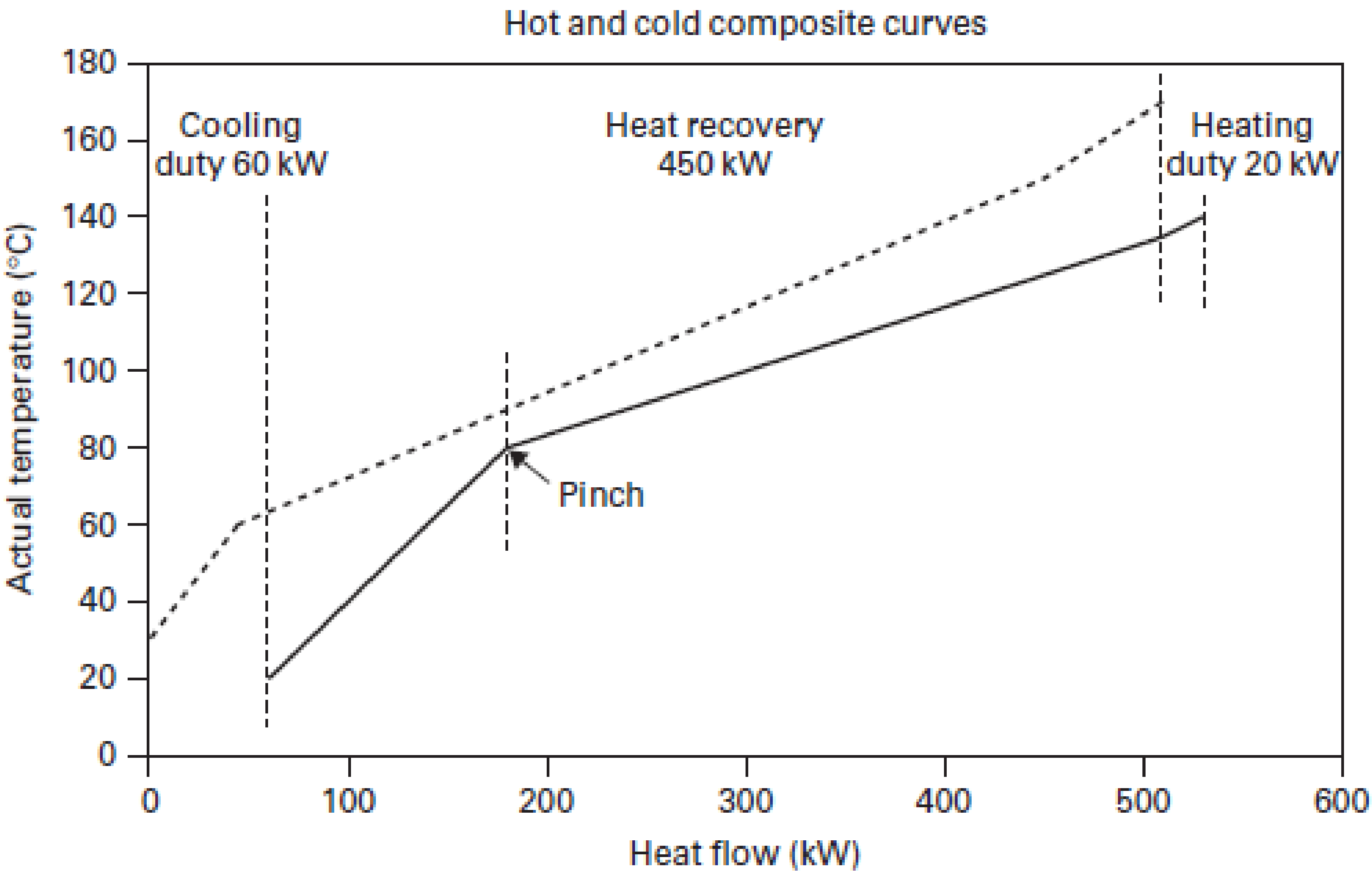


Hot and Cold Composites Combined

Heat recovery is possible where the hot composite is hotter than cold composite

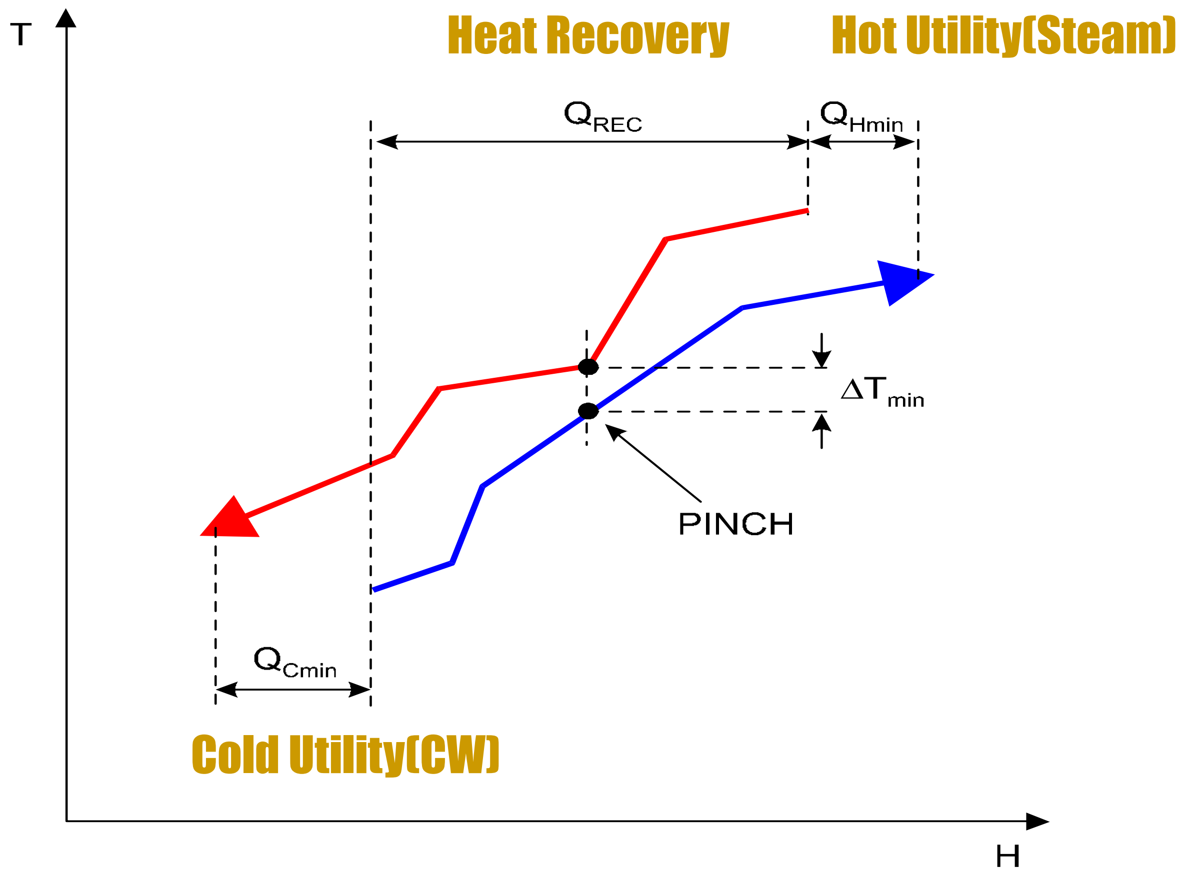


- For heat exchange to occur from the hot stream to the cold stream, the hot stream cooling curve must lie above the cold stream-heating curve. Because of the 'kinked' nature of the composite curves, they approach each other most closely at one point defined as the minimum approach temperature (ΔT_{min}).
- ΔT_{min} can be measured directly from the T-H profiles as being the minimum vertical difference between the hot and cold curves.
- This point of minimum temperature difference represents a bottleneck in heat recovery and is commonly referred to as the "Pinch".
- Increasing the ΔT_{min} value results in the shifting of the curves horizontally apart resulting in lower process to process heat exchange and higher utility requirements.
- At a particular ΔT_{min} value, the overlap shows the maximum possible scope for heat recovery within the process.
- The hot end and cold end overshoots indicate minimum hot utility requirement (Q_{Hmin}) and minimum cold utility requirement (Q_{Cmin}), of the process for the chosen ΔT_{min}.


Hot and cold composite curves
Cooling duty 60 kW
Heat recovery 450 kW
Heating duty 20 kW
Pinch
Actual temperature (°C)
Heat flow (kW)
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600

Composite Curve

- Energy Balance



- Thus, the energy requirement for a process is supplied via process to process heat exchange and/or exchange with several utility levels (steam levels, refrigeration levels, hot oil circuit, furnace flue gas, etc.).
- Graphical constructions are not the most convenient means of determining energy needs. A numerical approach called the **"Problem Table Algorithm"** (PTA) is also a means of determining the utility needs of a process and the location of the process pinch. The PTA lends itself to hand calculations of the energy targets.
- The composite curves provide overall energy targets but do not clearly indicate how much energy must be supplied by different utility levels. The utility mix is determined by the Grand Composite Curve.

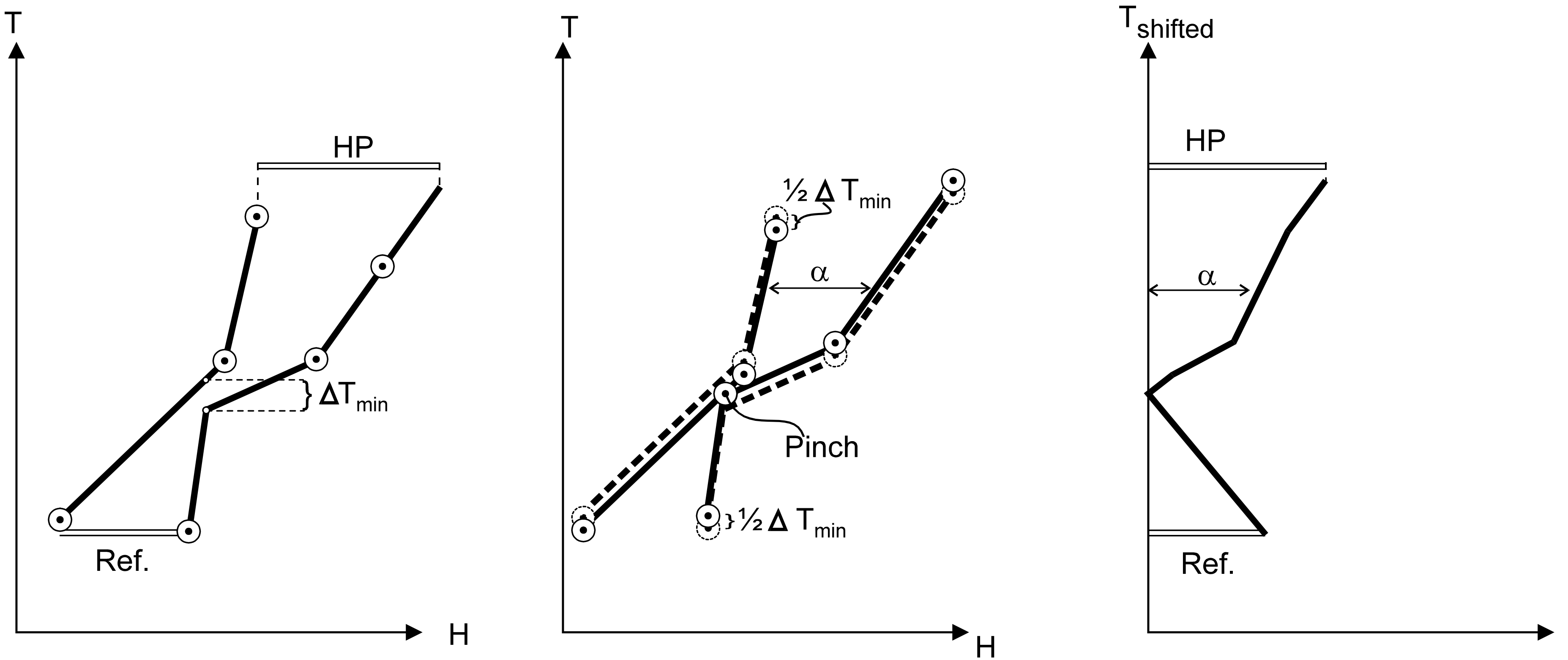
5. **Grand Composite Curve (GCC):**

- shows the variation of heat supply and demand within the process.
- Used to specify utilities to be used by maximizing the use of the cheaper utility levels and minimize the use of the expensive utility levels.
- Low-pressure steam and cooling water are preferred instead of high-pressure steam and refrigeration, respectively.

- The information required for the construction of the GCC comes directly from the PTA.
- The method involves shifting (along the temperature [Y] axis) of the hot composite curve down by ½ ΔT_{min} and that of cold composite curve up by ½ ΔT_{min}, i.e. the curves are shifted by subtracting part of the allowable temperature approach from the hot stream temperatures and adding the remaining part of the allowable temperature approach to the cold stream temperatures.
- The result is a scale based upon process temperature having an allowance for temperature approach (ΔT_{min}).
- The vertical axis on the shifted composite curves shows process interval temperature.
- The GCC indicates that we can supply the hot utility over two temperature levels T_{H1} (HPsteam) and T_{H2} (LP steam). Recall that, when placing utilities in the GCC, intervals, and not actual utility temperatures, should be used. The total minimum hot utility requirement remains the same: $Q_{Hmin} = H_1$ (HP steam) + H_2 (LP steam). Similarly, $Q_{Cmin} = C_1$ (Refrigerant) +C_2 (CW). The points T_{H2} and T_{C2} where the H_2 and C_2 levels touch the grand composite curve are called the **"Utility Pinches."** The shaded green pockets represent the process-to-process heat exchange.

Grand Composite Curve

- Tool that is used for setting multiple utility

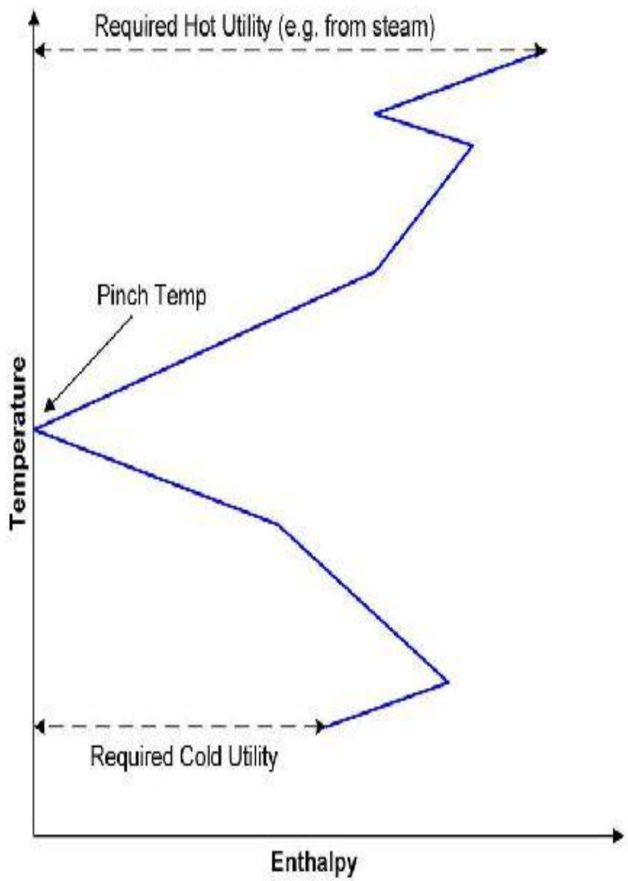


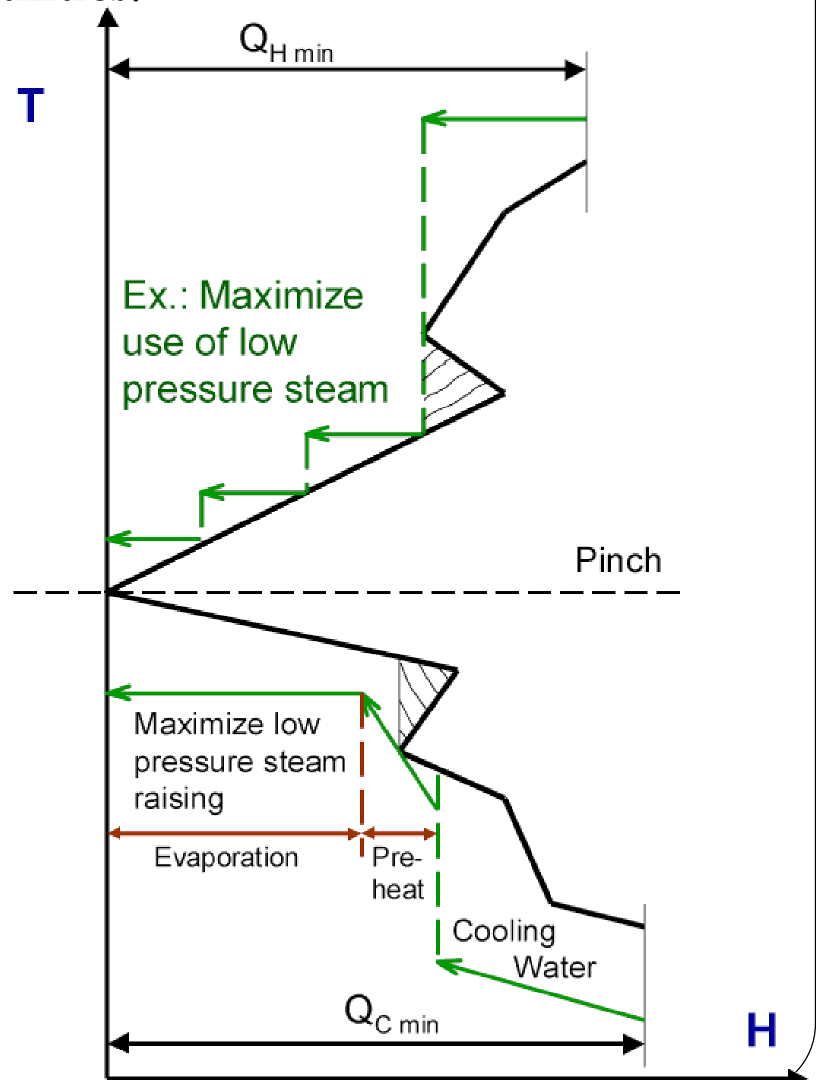
Composite Curves (a) | Shifted Composite Curves (b) | Grand Composite Curves (c)

- Shifted composite curve :

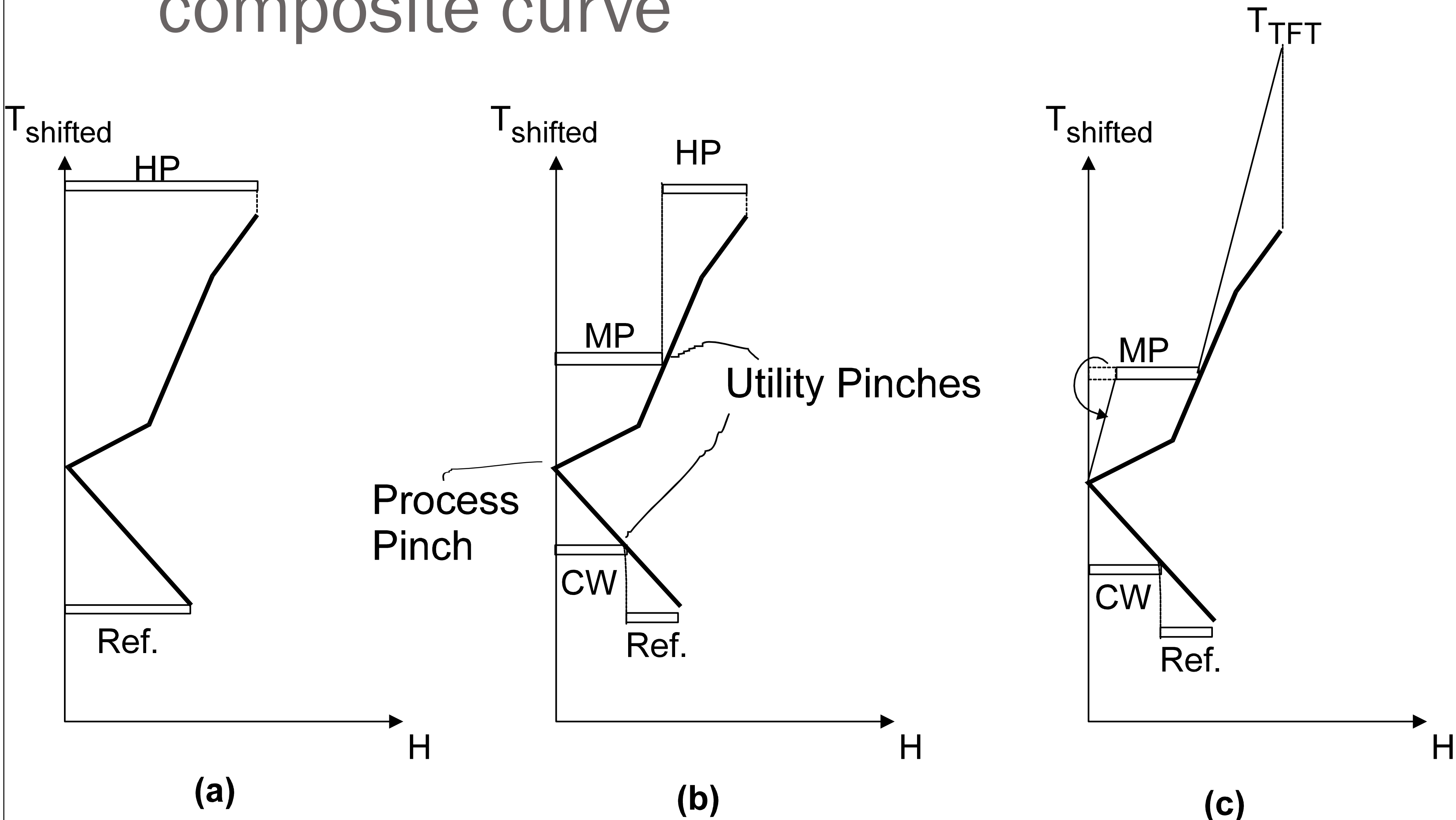
  utility level GCC utility process stream ΔT_{min}

- In summary, the GCC is one of the most basic tools used in pinch analysis for the selection of the appropriate utility levels and for targeting of a given set of multiple utility levels. The targeting involves setting appropriate loads for the various utility levels by maximizing the least expensive utility loads and minimizing the loads on the most expensive utilities.





Multiple utility targetting with grand composite curve



- utility level utility level targetting

6. **Estimation of Minimum Energy Cost Targets**: Once the ΔT_{min} is chosen, minimum hot and cold utility requirements can be evaluated from the composite curves. The GCC provides information regarding the utility levels selected to meet Q_{Hmin} and Q_{Cmin} requirements. If the unit cost of each utility is known, the total energy cost can be calculated using the energy equation given below.

$$\text{TOTAL ENERGY COST} = \sum_{U=1}^{U} Q_U \times C_U$$

Where Q_U = Duty of utility U , kW

C_U = Unit cost of utility U , \$/kW.yr

U = Total number of utilities used

7. **Estimation of Heat Exchanger Network (HEN) Capital Cost Targets:**

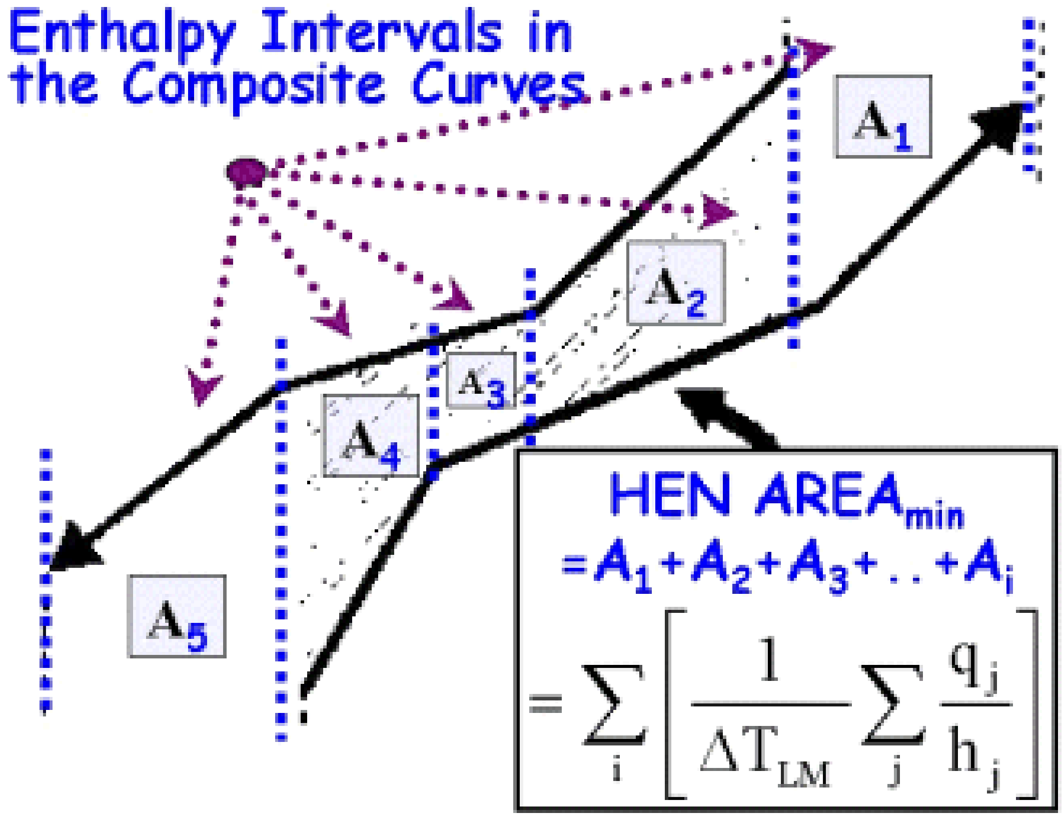
The capital cost of a HEN is dependent upon three factors:

- the number of exchangers,
- the overall network area, and
- the distribution of area between the exchangers.

Pinch analysis enables targets for the **overall heat transfer area** and **minimum number of units** of a HEN to be predicted prior to detailed design. Heat exchange area is evenly distributed between the units, and can't be predicted ahead of design.

a. Area targeting: The calculation of surface area for a single counter-current heat exchanger is given by the relation: Area = Q / [U x ΔT_{LM}]

- The total area of the HEN (A_{min}) is given by



where *i* denotes the *i*th enthalpy and interval *j* denotes the *j*th stream and ΔT_{LM} denotes LMTD in the *i*th interval

b. Number of units targeting: For the minimum number of heat exchanger units (N_{min}) required for MER (minimum energy requirement or maximum energy recovery), the HEN can be evaluated prior to its design by using a simplified form of Euler's graph theorem.

In designing for the minimum energy requirement (MER), no heat transfer is allowed across the pinch and so a realistic target for the minimum number of units (N_{minMER}) is the sum of the targets evaluated both above and below the pinch separately.

$$\mathbf{N_{minMER} = [N_h + N_c + N_u - 1]_{AP} + [N_h + N_c + N_u - 1]_{BP}}$$

- where: N_h = Number of hot streams, N_c=Number of cold streams, N_u = Number of utility streams, AP / BP : Above / Below Pinch

c. HEN total capital cost targeting: The targets for the minimum surface area (A_{min}) and the number of units (N_{min}) can be combined together with the heat exchanger cost law to determine the targets for HEN capital cost (C_{HEN}). The capital cost is annualized using an annualization factor that takes into account interest payments on borrowed capital. The equation used for calculating the total capital cost and exchanger cost law is given below.

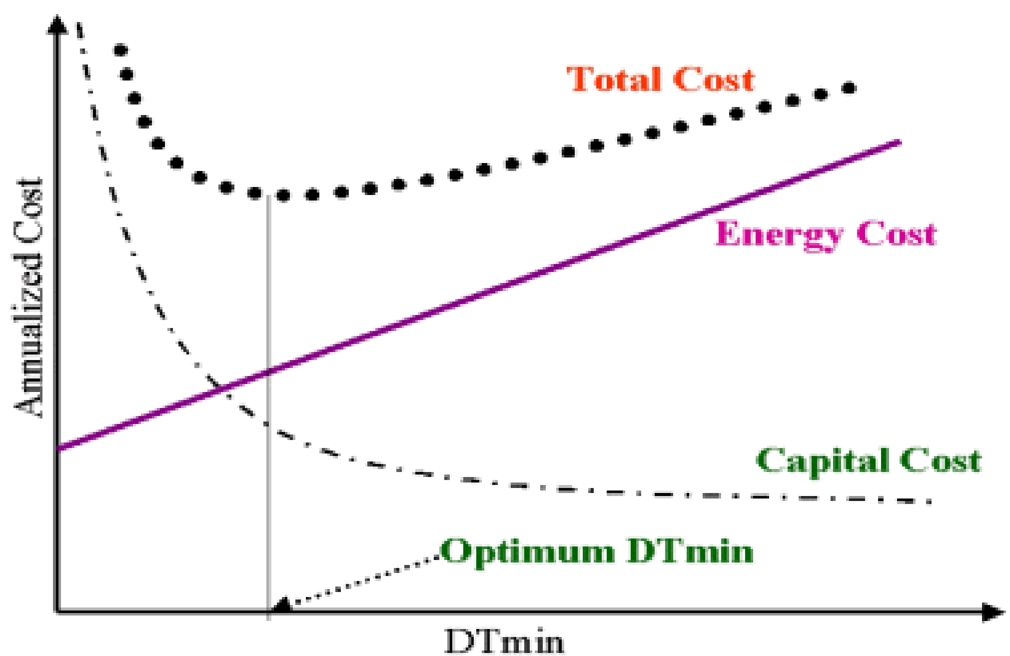
$$C(\$)_{HEN} = [N_{min}\{a + b(A_{min} / N_{min})^c\}]_{AP}$$

$$+ [N_{min}\{a + b(A_{min} / N_{min})^c\}]_{BP}$$

where a ,b, and c are constants in exchanger cost law

Exchanger cost ($) = a + b (Area)^c

8. **Estimation of Optimum ΔT_{min} Value by Energy-Capital Trade Off**: To arrive at an optimum ΔT_{min} value, the total annual cost (the sum of total annual energy and capital cost) is plotted at varying ΔT_{min} values.



Three key observations can be made from Figure above:

- An increase in ΔTmin values result in higher energy costs and lower capital costs.
- A decrease in ΔTmin values result in lower energy costs and higher capital costs.
- An optimum ΔTmin exists where the total annual cost of energy and capital costs is minimized.

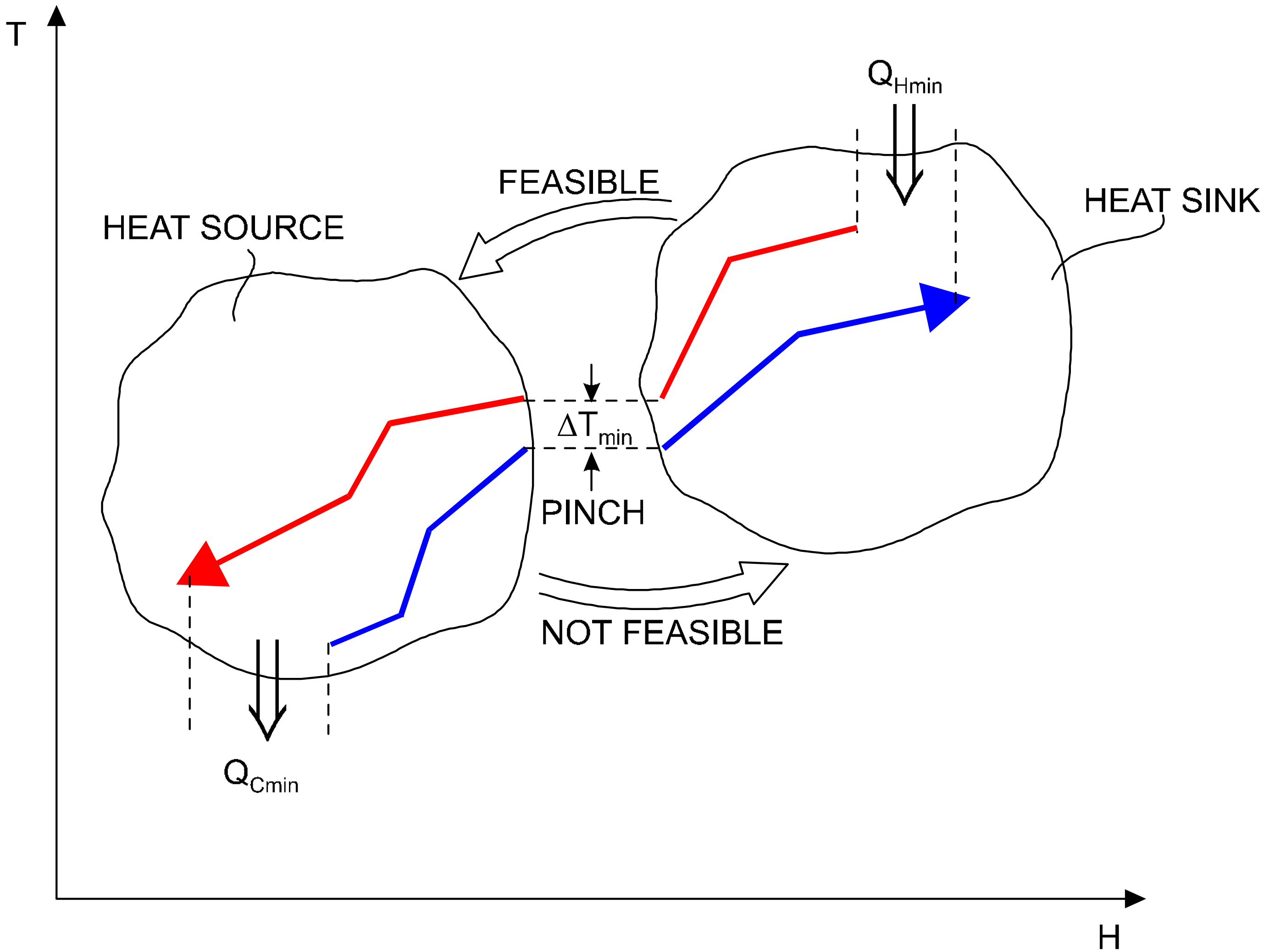
- Thus, by systematically varying the temperature approach we can determine the optimum heat recovery level or the $\Delta Tmin_{OPTIMUM}$ for the process.

9. **<u>Estimation of Practical Targets for HEN Design</u>**: The HEN designed on the basis of the estimated optimum ΔTmin value is not always the most appropriate design.
    - A very small ΔT_{min} value, perhaps 8^0C, can lead to a very complicated network design with a large total area due to low driving forces.
    - In practice, a higher value (15^0C) is selected and the marginal increases in utility duties and area requirements calculated.
    - If the marginal cost increase is small, the higher value of ΔT_{min} is selected as the practical pinch point for the HEN design.

- The significance of the pinch temperature allows energy targets to be realized by design of appropriate HEN.
    - The **pinch** divides the process into two separate systems each of which is in enthalpy balance with the utility.
    - The pinch point is unique for each process.
    - Above the pinch, only the hot utility is required.
    - Below the pinch, only the cold utility is required.
    - For an optimum design, no heat should be transferred across the pinch. ***This is the key concept in Pinch Technology***.
- Pinch Technology gives three rules that form the basis for practical network design:
    - No external heating below the Pinch.
    - No external cooling above the Pinch.
    - No heat transfer across the Pinch.
- *Violation of any of the above rules results in higher energy requirements than the minimum requirements theoretically possible.*

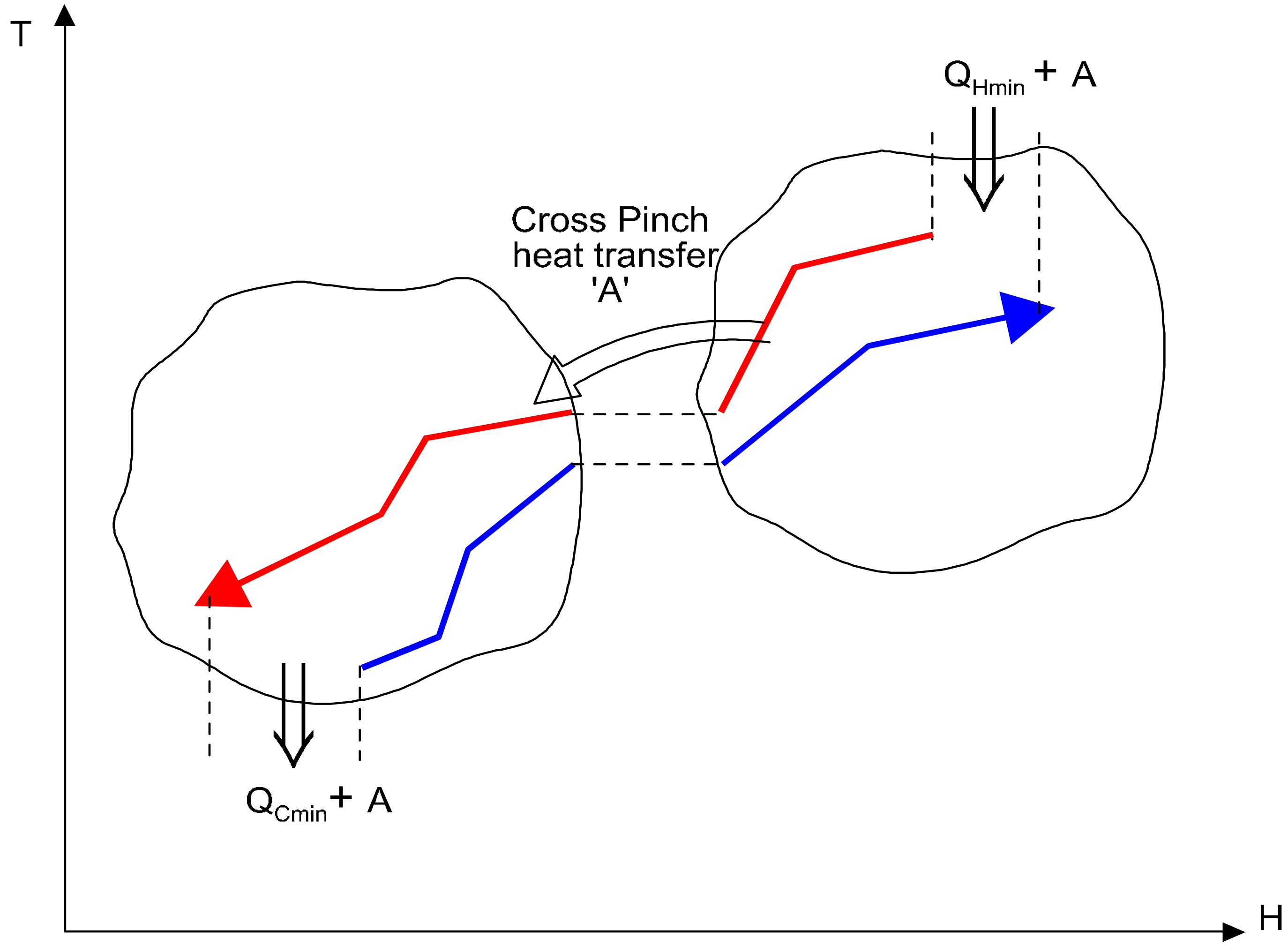
Pinch principle

- Heat must not be transferred across the pinch
- There must be no external cooling above the pinch
- There must be no external heating below the pinch



Pinch Principle

- Cross Pinch



10. **<u>Plus/Minus Principle</u>:** The overall energy needs of a process can be further reduced by introducing *process changes* (changes in the process heat and material balance). There are several parameters that could be changed such as DC operating pressures and reflux ratios, feed vaporization pressures, or pump-around flow rates. The number of possible process changes is nearly infinite. By applying the pinch rules, it is possible to identify changes in the appropriate process parameter that will have a favorable impact on energy consumption. This is called the "Plus/Minus Principle."

- Applying the pinch rules to study of composite curves provides us the following guidelines:
  - Increase (+) in hot stream duty above the pinch and Decrease (-) in cold stream duty above the pinch, will result in a reduced hot utility target, and any
  - Decrease (-) in hot stream duty below the pinch and Increase (+) in cold stream duty below the pinch, will result in a reduced cold utility target.
- These guidelines provide a definite reference for the adjustment of single heat duties such as vaporization of a recycle, pump-around condensing duty, etc. Often it is possible to change temperatures rather than the heat duties. The target should be to
  - Shift hot streams from below the pinch to above and
  - Shift cold streams from above the pinch to below.

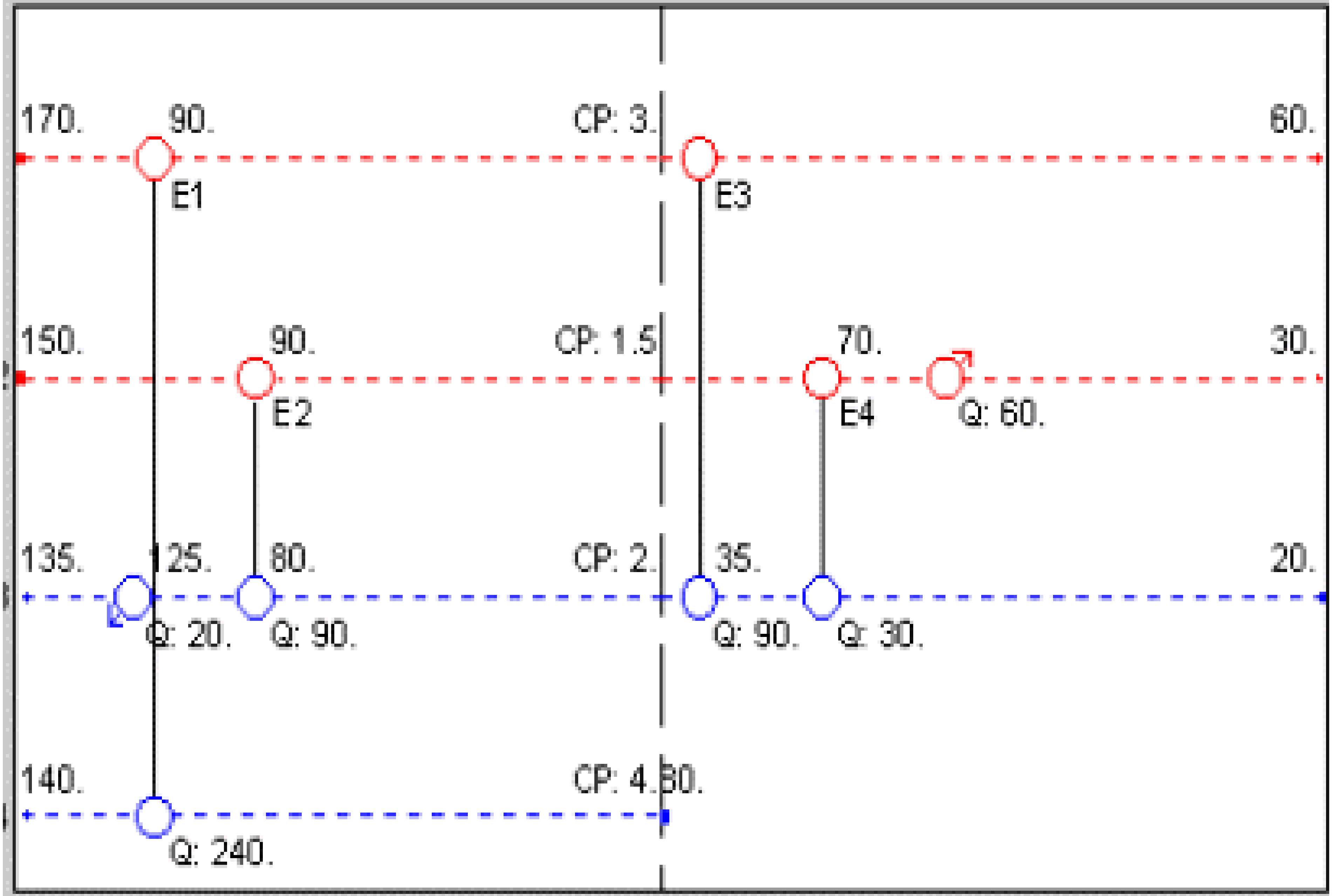
11. **Appropriate Placement Principles:** Apart from the changes in process parameters, proper integration of key equipment in process with respect to the pinch point should also be considered. The pinch concept of "Appropriate Placement" (integration of operations in such a way that there is reduction in the utility requirement of the combined system) is used for this purpose. Appropriate placement principles have been developed for DCs, evaporators, heat engines, furnaces, and heat pumps.

- In addition to the above pinch rules and principles, a large number of factors must also be considered during the design of HENs. The most important are operating cost, capital cost, safety, operability, future requirements, and plant operating integrity. **Operating costs** are dependent on hot and cold utility requirements as well as pumping and compressor costs. **The capital cost** of a network is dependent on a number of factors including the number of heat exchangers, heat transfer areas, materials of construction, piping, and the cost of supporting foundations and structures.
- The essence of the pinch approach is to explore the options of modifying the core process design, heat exchangers, and utility systems with the ultimate goal of reducing the energy and/or capital cost.

12. **<u>Design of Heat Exchanger Network</u>**: The design of a new HEN is best executed using the "Pinch Design Method (PDM)".

- The systematic application of the PDM allows the design of a good network that achieves the energy targets within practical limits. The method incorporates two fundamentally important features:
  - it recognizes that the pinch region is the most constrained part of the problem (consequently it starts the design at the pinch and develops by moving away) and,
  - it allows the designer to choose between match options.

- Network design examines which "hot" streams can be matched to "cold" streams via heat recovery. This can be achieved by employing "tick off" heuristics to identify the heat loads on the pinch exchanger.
  - Every match brings one stream to its target temperature.
  - The pinch divides the heat exchange system into two thermally independent regions, HENs for both above and below pinch regions are designed separately.
  - When the heat recovery is maximized the remaining thermal needs must be supplied by hot utility. The graphical method of representing flow streams and heat recovery matches is called a ‘grid diagram’.



Typical grid diagram

- All the cold and hot streams are represented by horizontal lines.
- The entrance and exit temperatures are shown at either end.
- The vertical line in the middle represents the pinch temperature.
- The circles represent heat exchangers. Unconnected circles represent exchangers using utility heating and cooling.
- The design of a network is based on certain guidelines like the "C_P Inequality Rule", "Stream Splitting", "Driving Force Plot" and "Remaining Problem Analysis".
- Having made all the possible matches, the two designs above and below the pinch are then brought together and usually refined to further minimize the capital cost.
- After the network has been designed according to the pinch rules, it can be further subjected to energy optimization.
- Optimizing the network involves both topological and parametric changes of the initial design in order to minimize the total cost.


Thank You!