

Pinch Technology: Basics for the Beginners

Introduction

While oil prices continue to climb, energy conservation remains the prime concern for many process industries. The challenge every process engineer is faced with is to seek answers to questions related to their process energy patterns. A few of the frequently asked questions are:

- Are the existing processes as energy efficient as they should be?
- How can new projects be evaluated with respect to their energy requirements?
- What changes can be made to increase the energy efficiency without incurring any cost?
- What investments can be made to improve energy efficiency?
- What is the most appropriate utility mix for the process?
- How to put energy efficiency and other targets like reducing emissions, increasing plant capacities, improve product qualities etc, into a one coherent strategic plan for the overall site?

All of these questions and more can be answered with a full understanding of **Pinch Technology** and an awareness of the available tools for applying it in a practical way. This article aims to provide the basic knowledge of the concepts in pinch technology and how they have been applied across a wide range of process industries.

The article comprises of following six sections:

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- Conclusions
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- Web links

What is Pinch Technology?

Meaning of the term “Pinch Technology”

The term “Pinch Technology” was introduced by Linnhoff and Vredeveld to represent a new set of thermodynamically based methods that guarantee minimum energy levels in design of heat exchanger networks. Over the last two decades it has emerged as an unconventional development in process design and energy conservation. The term **‘Pinch Analysis’** is often used to represent the application of the tools and algorithms of Pinch Technology for studying industrial processes. Developments of rigorous software programs like PinchExpress™, SuperTarget™, Aspen Pinch™ have proved to be very useful in pinch analysis of complex industrial processes with speed and efficiency. Check out [Link-1](#) for their demos at the end of the article.

Basis of Pinch Analysis

Pinch technology presents a simple methodology for systematically analysing chemical processes and the surrounding utility systems with the help of the First and Second Laws of Thermodynamics. The **First Law** of Thermodynamics provides the energy equation for calculating the enthalpy changes (ΔH) in the streams passing through a heat exchanger. The **Second Law** determines the direction of heat flow. That is, heat energy may only flow in the direction of hot to cold. This prohibits ‘*temperature crossovers*’ of the hot and cold stream profiles through the exchanger unit. In a heat exchanger unit neither a hot stream can be cooled below cold stream supply temperature nor a cold stream can be heated to a temperature more than the supply temperature of hot stream. In practice the hot stream can only be cooled to a temperature defined by the ‘*temperature approach*’ of the heat exchanger. The temperature approach is the minimum allowable temperature difference (DTmin) in the stream temperature profiles, for the heat exchanger unit. The temperature level at which DTmin is observed in the process is referred to as “**pinch point**” or “**pinch condition**”. The pinch defines the minimum driving force allowed in the exchanger unit. The basic concepts of Pinch Analysis are discussed in [Section-2](#).

Objectives of Pinch Analysis

Pinch Analysis is used to identify energy cost and heat exchanger network (HEN) capital cost targets for a process and recognizing the pinch point. The procedure first predicts, ahead of design, the minimum requirements of external energy, network area, and the number of units for a given process at the pinch point. Next a heat exchanger network design that satisfies these targets is synthesized. Finally the network is optimized by comparing energy cost and the capital cost of the network so that the total annual cost is minimized. **Thus, the prime objective of pinch analysis is to achieve financial savings by better process heat integration (maximizing process-to-process heat recovery and reducing the external utility loads).** The concept of process heat integration is illustrated in the example discussed below.

A Simple Example of Process Integration by Pinch Analysis

Consider the following simple process [Fig 1(a)] where feed stream to a reactor is heated before inlet to a reactor and the product stream is to be cooled. The heating and cooling are done by use of steam (Heat Exchanger -1) and cooling water (Heat Exchanger-2), respectively. The Temperature (T) vs. Enthalpy (H) plot for the feed and product streams depicts the hot (Steam) and cold (CW) utility loads when there is no vertical overlap of the hot and cold stream profiles.

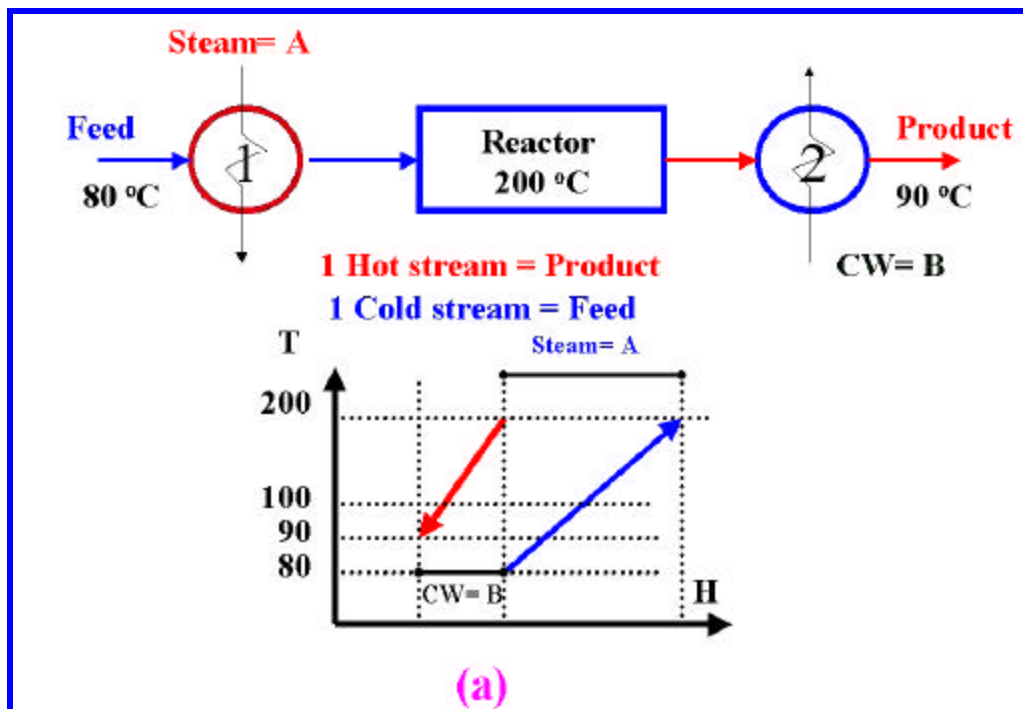


Figure 1(a): A Simple Flow Scheme with T-H profile.

An alternative, improved scheme is shown in Figure 1(b) where the addition of a new 'Heat Exchanger-3' recovers product heat (X) to preheat the feed. The steam and cooling water requirements also get reduced by the same amount (X). The amount of heat recovered (X) depends on the 'minimum approach temperature' allowed for the new exchanger. The minimum temperature approach between the two curves on the vertical axis is DT_{min} and the point where this occurs is defined as the "**pinch**". From the T-H plot, the X amount corresponds to a DT_{min} value of 20 °C. Increasing the DT_{min} value leads to higher utility requirements and lower area requirements. The estimation of optimum economic value of DT_{min} is discussed in the [Section -3](#).

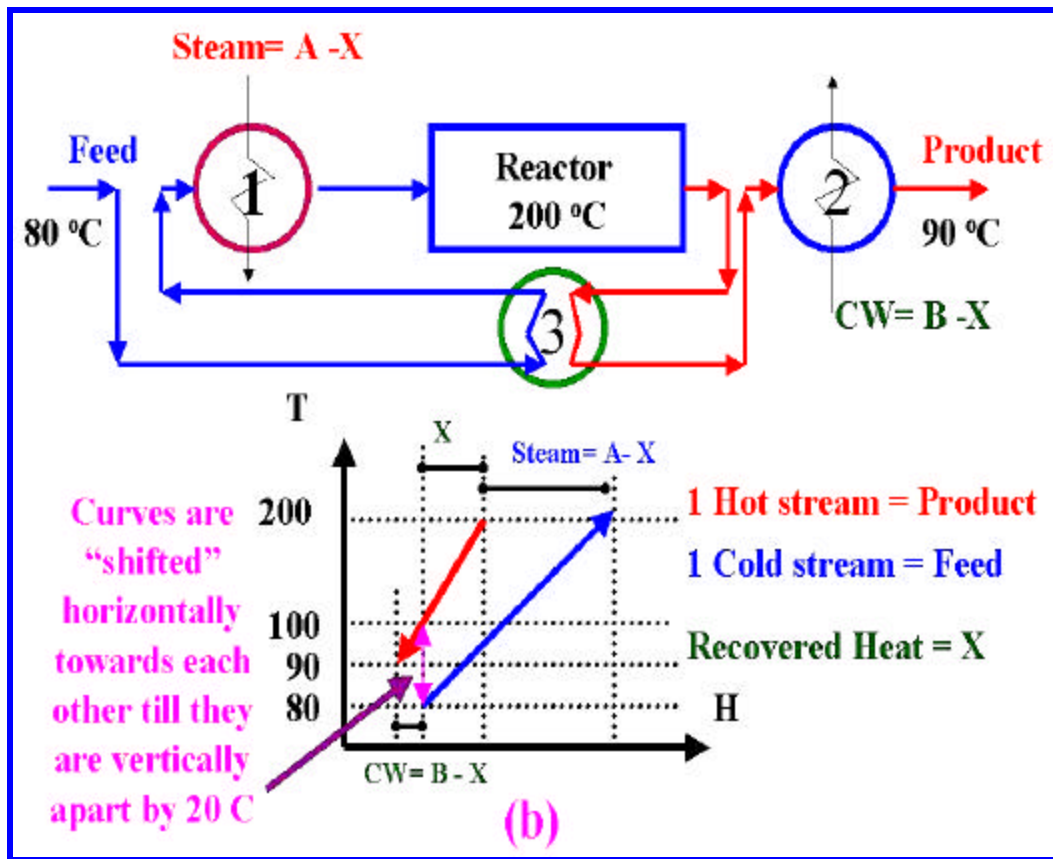


Figure 1(b): Improved Flow Scheme with T-H profile.

Development of the Pinch Technology Approach

When the process involves single hot and cold streams (as in above example) it is easy to design an optimum heat recovery exchanger network intuitively by heuristic methods. In any industrial set-up the number of streams is so large that the traditional design approach has been found to be limiting in the design of a good network. With the development of pinch technology in the late 1980's, not only optimal network design was made possible, but also considerable process improvements could be discovered. Both the traditional and pinch approaches are depicted in Figure 2.

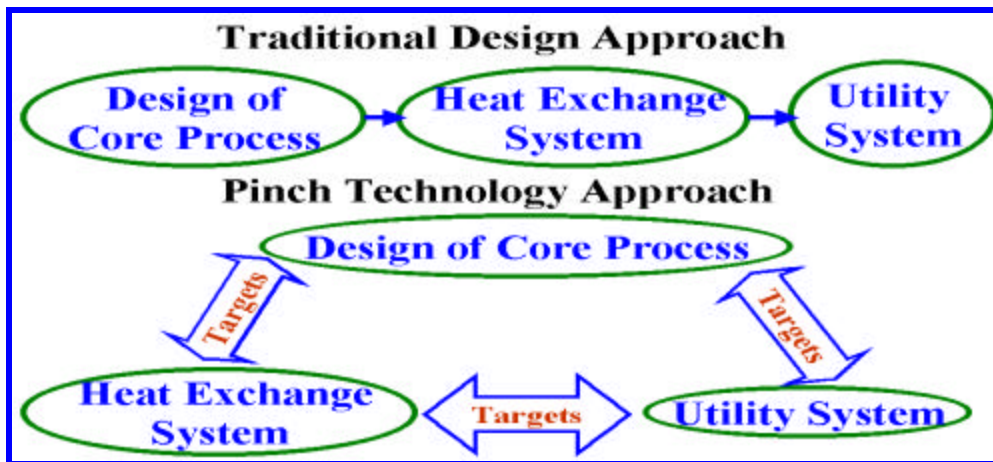


Figure 2: Graphic Representation of Traditional & Pinch Design Approaches

Traditional Design Approach: First, the core of the process is designed with fixed flow rates and temperatures yielding the heat and mass balance for the process. Then the design of a heat recovery system is completed. Next, the remaining duties are satisfied by the use of the utility system. Each of these exercises is performed independently of the others.

Pinch Technology Approach: Process integration using pinch technology offers a novel approach to generate targets for minimum energy consumption before heat recovery network design. Heat recovery and utility system constraints are then considered in the design of the core process. Interactions between the heat recovery and utility systems are also considered. The pinch design can reveal opportunities to modify the core process to improve heat integration. The pinch approach is unique because it treats all processes with multiple streams as a single, integrated system. This method helps to optimize the heat transfer equipment during the design of the equipment. The steps of pinch analysis are discussed in detail in the [Section 3](#).

Areas of Applications of Pinch Technology

Pinch originated in the petrochemical sector and is now being applied to solve a wide range of problems in mainstream chemical engineering. Wherever heating and cooling of process materials takes place there is a potential opportunity. Thus initial applications of the technology were found in projects relating to energy saving in industries as diverse as iron and steel, food and drink, textiles, paper and cardboard, cement, base chemicals, oil, and petrochemicals.

Early emphasis on energy conservation led to the misconception that conservation is the main area of application for pinch technology. The technology, when applied with imagination, can affect reactor design, separator design, and the overall process optimization in any plant. It has been applied to processing problems that go far beyond energy conservation. It has been employed to solve problems as diverse as improving effluent quality, reducing emissions, increasing product yield, debottlenecking, increasing throughput, and improving the flexibility and safety of the processes.

Since its commercial introduction, pinch technology has achieved an outstanding record of success in the design and retrofit of chemical manufacturing facilities. Documented results reported in the literature show that energy costs have been reduced by 15-40%, capacity debottlenecking achieved by 5-15% for retrofits, and capital cost reduction of 5-10% for new designs. The general benefits and applications of pinch technology are discussed in brief in the [Section 4](#).

Basic Concepts of Pinch Analysis

Most industrial processes involve transfer of heat either from one process stream to another process stream (interchanging) or from a utility stream to a process stream. In the present energy crisis scenario all over the world, the target in any industrial process design is to maximize the process-to-process heat recovery and to minimize the utility (energy) requirements. To meet the goal of maximum energy recovery or minimum energy requirement (MER) an appropriate heat exchanger network (HEN) is required. The design of such a network is not an easy task considering the fact that most processes involve a large number of process and utility streams. As explained in the previous section, the traditional design approach has resulted in networks with high capital and utility costs. With the advent of pinch analysis concepts, the network design has become very systematic and methodical.

A summary of the key concepts, their significance, and the nomenclature used in pinch analysis is given below:

- **Combined (Hot and Cold) Composite Curves:** Used to predict targets for
 - Minimum energy (both hot and cold utility) required,
 - Minimum network area required, and
 - Minimum number of exchanger units required.
- **DTmin and Pinch Point:** The DTmin value determines how closely the hot and cold composite curves can be 'pinched' (or squeezed) without violating the Second Law of Thermodynamics (none of the heat exchangers can have a temperature crossover).
- **Grand Composite Curve:** Used to select appropriate levels of utilities (maximize cheaper utilities) to meet over all energy requirements.
- **Energy and Capital Cost Targeting:** Used to calculate total annual cost of utilities and capital cost of heat exchanger network.
- **Total Cost Targeting:** Used to determine the optimum level of heat recovery or the optimum DTmin value, by balancing energy and capital costs. Using this method, it is possible to obtain an accurate estimate (within 10 - 15%) of overall heat recovery system costs without having to design the system. The essence of the pinch approach is the speed of economic evaluation.
- **Plus/Minus and Appropriate Placement Principles:** The "*Plus/Minus*" Principles provide guidance regarding how a process can be modified in order to reduce associated utility needs and costs. The *Appropriate Placement Principles* provide insights for proper integration of key equipments like distillation columns, evaporators, furnaces, heat engines, heat pumps etc. in order to reduce the utility requirements of the combined system.

- **Total Site Analysis:** This concept enables the analysis of the energy usage for an entire plant site that consists of several processes served by a central utility system.

With further research, new topics like 'Regional Energy Analysis', 'Network Pinch', 'Top Level Analysis', 'Optimisation of Combined Heat & Power', 'Water Pinch', 'Hydrogen Pinch' etc. Are being developed. These pinch concepts are discussed in [Section-3 and 5](#) **These basic terms and concepts have become the foundation of what we now call Pinch Technology.**

Steps of Pinch Analysis

In any Pinch Analysis problem, whether a new project or a retrofit situation, a well-defined stepwise procedure is followed (Figure 3). It should be noted that these steps are not necessarily performed on a once-through basis, independent of one another. Additional activities such as re-simulation and data modification occur as the analysis proceeds and some iteration between the various steps is always required.

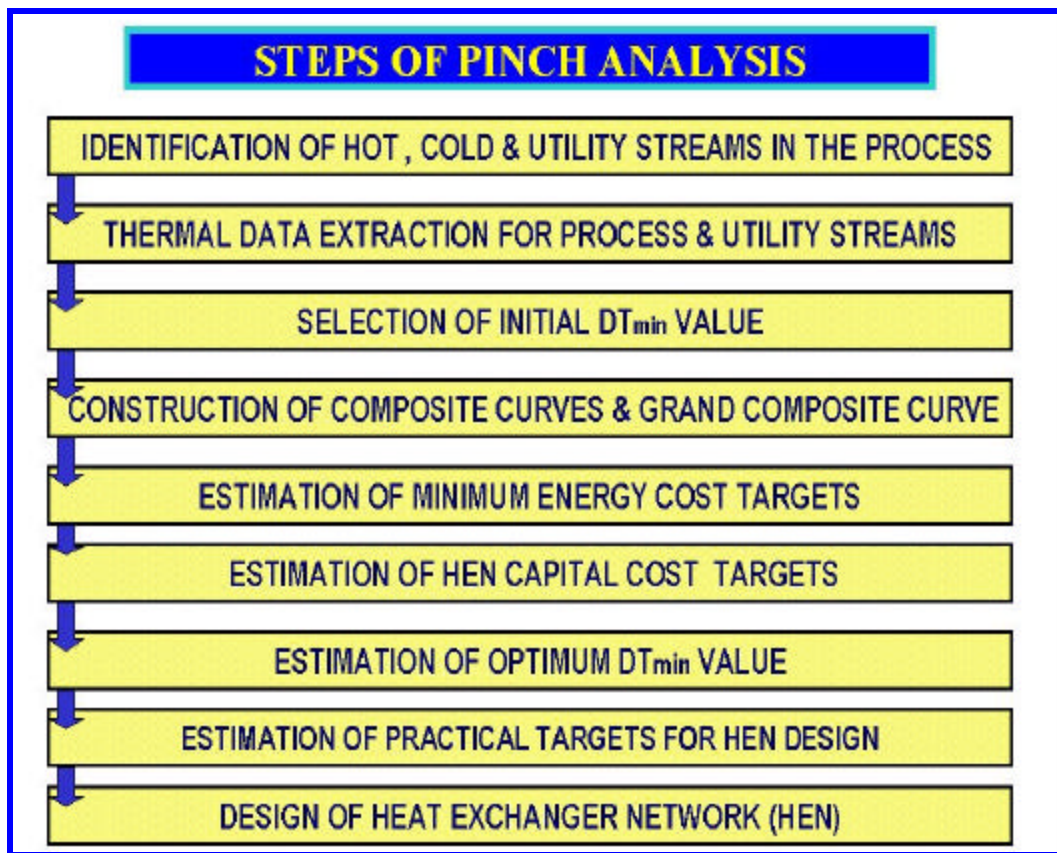


Figure 3: Steps of Pinch Analysis

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. A number of different **hot utilities** (steam, hot water, flue gas, etc.) and **cold utilities** (cooling water, air, refrigerant, etc.) are used in industry.

The identification of streams needs to be done with care as sometimes, despite undergoing changes in temperature, the stream is not available for heat exchange. For example, when a gas stream is compressed the stream temperature rises because of the conversion of mechanical energy into heat and not by any fluid to fluid heat exchange. Hence such a stream may not be available to take part in any heat exchange. In the context of pinch analysis, this stream may or may not be considered to be a process stream.

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:

- **Supply temperature (TS °C)** : the temperature at which the stream is available.
- **Target temperature (TT °C)** : the temperature the stream must be taken to.
- **Heat capacity flow rate (CP kW/ °C)** : the product of flow rate (m) in kg/sec and specific heat (Cp kJ/kg °C).

$$CP = m \times Cp$$

- **Enthalpy Change (H)** associated with a stream passing through the exchanger is given by the First Law of Thermodynamics:

First Law energy equation: $H = Q \pm W$

In a heat exchanger, no mechanical work is being performed:

$$W = 0 \text{ (zero)}$$

The above equation simplifies to: $H = Q$ where Q represents the heat supply or demand associated with the stream. It is given by the relationship: $Q = CP \times (TS - TT)$.

$$\text{Enthalpy Change, } H = CP \times (TS - TT)$$

*** Here the specific heat values have been assumed to be temperature independent within the operating range.*

The stream data and their potential effect on the conclusions of a pinch analysis should be considered during all steps of the analysis. Any erroneous or incorrect data can lead to false conclusions. In order to avoid mistakes, the data extraction is based on certain qualified principles. For details on principles of data extraction, check out **Link-2** at the end of the article. The data extracted is presented in Table 1.

TABLE 1: TYPICAL STREAM DATA

STREAM NUMBER	STREAM NAME	SUPPLY TEMP. °C	TARGET TEMP. °C	HEAT CAP. FLOW. kW /°C	ENTH. CHANGE kW
1	FEED	60	205	20	2900
2	REAC.OUT	270	160	18	1980
3	PRODUCT	220	70	35	5250
4	RECYCLE	160	210	50	2500

3. Selection of Initial DTmin value

The design of any heat transfer equipment must always adhere to the Second Law of Thermodynamics that prohibits any temperature crossover between the hot and the cold stream i.e. a minimum heat transfer driving force must always be allowed for a feasible heat transfer design. Thus the temperature of the hot and cold streams at any point in the exchanger must always have a minimum temperature difference (DTmin). This DTmin value represents the bottleneck in the heat recovery.

In mathematical terms, at any point in the exchanger

$$\text{Hot stream Temp. (} T_H \text{) - (} T_C \text{) Cold stream Temp. = DTmin}$$

The value of DTmin 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 D_{tmin} for the network. For example, an initial selection for the D_{tmin} value for shell and tubes may be 3-5 °C (at best) while compact exchangers such as plate and frame often allow for an initial selection of 2-3 °C. The heat transfer equation, which relates Q, U, A and LMTD (Log Mean Temperature Difference) is depicted in Figure 4.

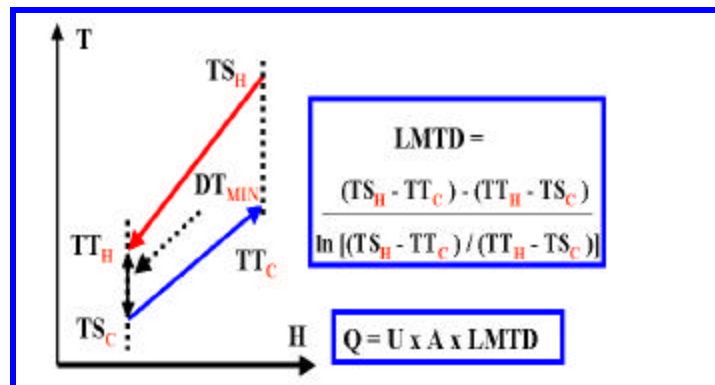


Figure 4: Heat Transfer Equation

For a given value of heat transfer load (Q), if smaller values of DTmin are chosen, the area requirements rise. If a higher value of DTmin is selected the heat recovery in the exchanger decreases and demand for external utilities increases. **Thus, the selection of DTmin value has implications for both capital and energy costs.** This concept will become clearer with the help of composite curves and total cost targeting discussed later.

Just as for a single heat exchanger, the choice of DTmin (or approach temperature) is vital in the design of a heat exchanger networks. To begin the process an initial DTmin value is chosen and pinch analysis is carried out. Typical DTmin values based on experience are available in literature for reference. A few values based on Linnoff March's application experience are tabulated below for shell and tube heat exchangers.

No	Industrial Sector	Experience DT _{min} Values
1	Oil Refining	20-40°C
2	Petrochemical	10-20°C
3	Chemical	10-20°C
4	Low Temperature Processes	3-5°C

For more details on typical DTmin values, check **Link-3** at the end of the article.

4. Construction of Composite Curves and Grand Composite Curve

- COMPOSITE CURVES:** Temperature - Enthalpy (T - H) plots known as 'Composite curves' have been used for many years to set energy targets ahead of design. Composite curves 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.

In general any stream with a constant heat capacity (CP) value is represented on a T - H diagram by a straight line running from stream supply temperature to stream target temperature. 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. An example of hot composite curve construction is shown in Figure 5(a) and (b). 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).

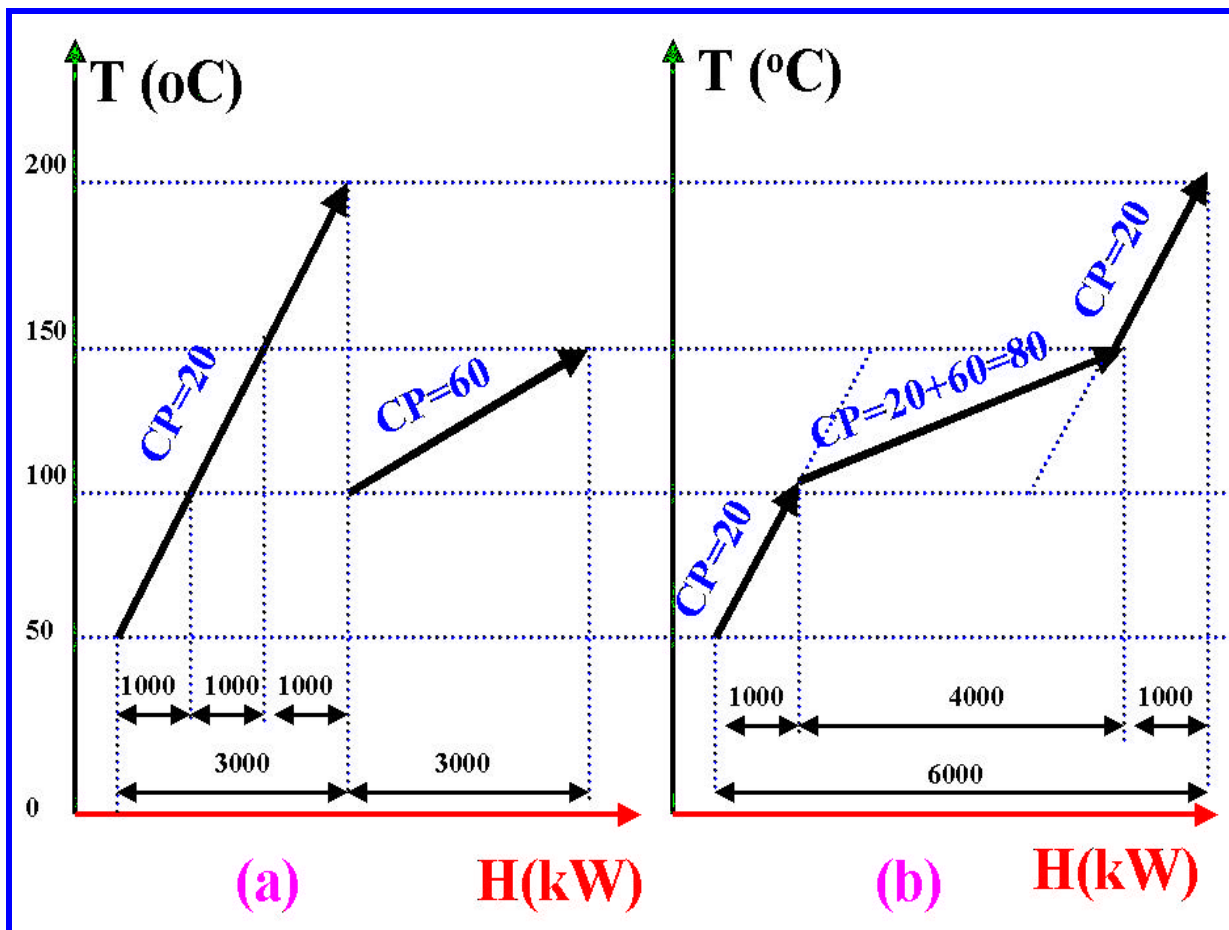


Figure 5: Temperature-Enthalpy Relations Used to Construct Composite Curves

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 (Figure 6), they approach each other most closely at one point defined as the minimum approach temperature (DTmin). DTmin 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 DTmin value results in shifting the of

the curves horizontally apart resulting in lower process to process heat exchange and higher utility requirements. At a particular DT_{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 (QH_{min}) and minimum cold utility requirement (QC_{min}), of the process for the chosen DT_{min} .

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) was developed by Linnhoff & Flower (1978) as 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. For more details on PTA see **Link-4** at the end of the article.

To summarize, 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.

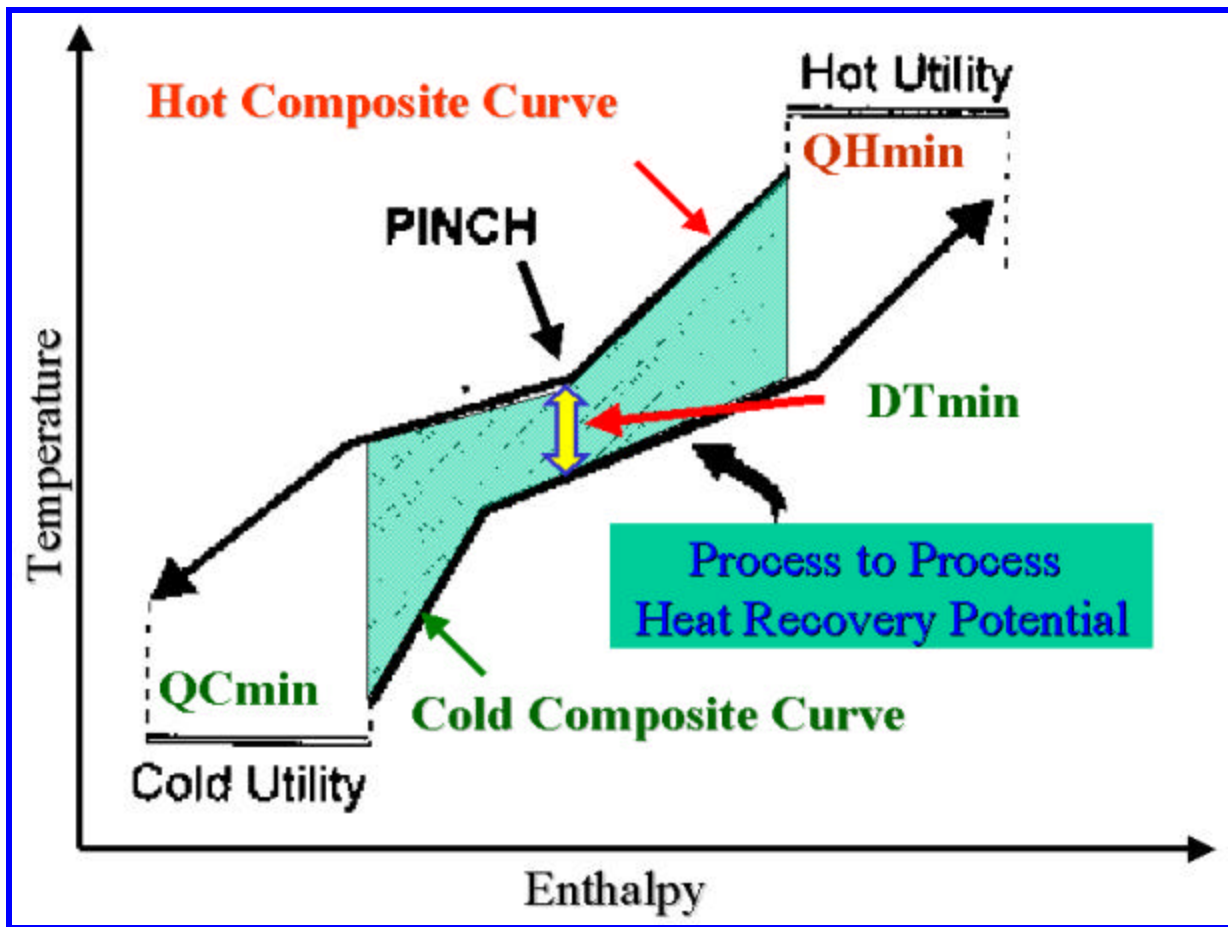


Figure 6: Combined Composite Curves

- GRAND COMPOSITE CURVE (GCC):** In selecting utilities to be used, determining utility temperatures, and deciding on utility requirements, the composite curves and PTA are not particularly useful. The introduction of a new tool, the Grand Composite Curve (GCC), was introduced in 1982 by Itoh, Shiroko and Umeda. The GCC (Figure 7) shows the variation of heat supply and demand within the process. Using this diagram the designer can find which utilities are to be used. The designer aims to maximize 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 Problem Table Algorithm developed by Linnhoff & Flower (1978). The method involves shifting (along the temperature [Y] axis) of the hot composite curve down by $\frac{1}{2} DT_{min}$ and that of cold composite curve up by $\frac{1}{2} DT_{min}$. The vertical axis on the shifted composite curves shows process interval temperature. In other words, 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 (DT_{min}). The Grand Composite Curve is then constructed from the enthalpy (horizontal) differences between the shifted composite curves at different temperatures. On the GCC, the horizontal distance separating the curve from the vertical axis at the top of the temperature scale shows the overall hot utility consumption of the process.

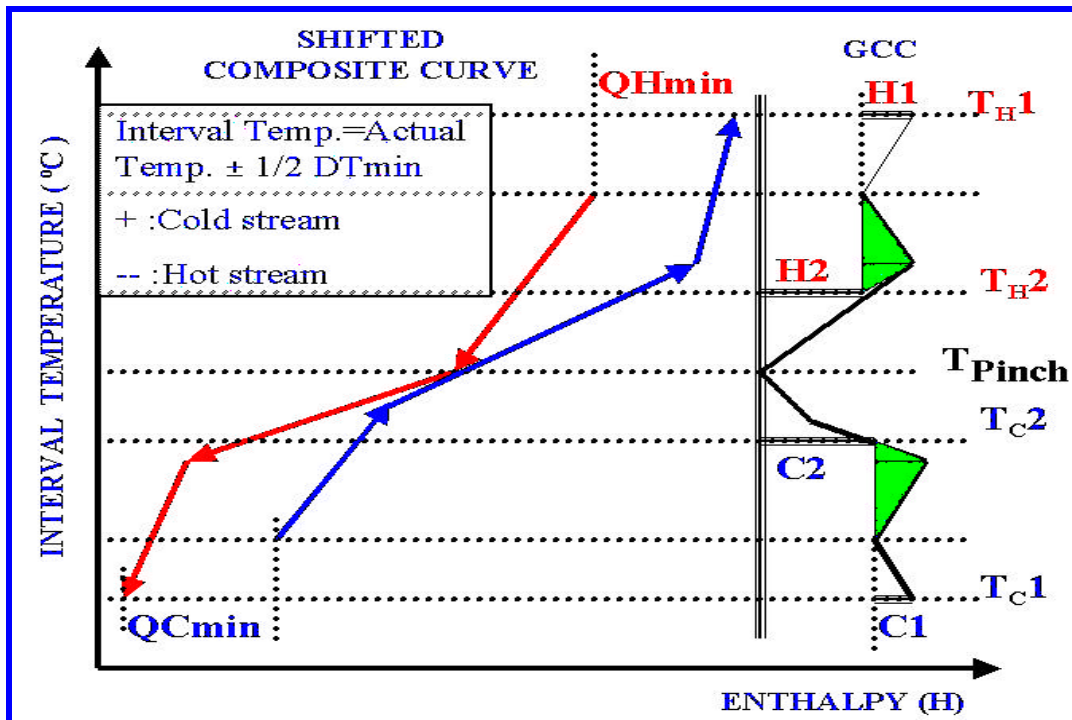


Figure 7: Grand Composite Curve

Figure 7 shows that it is not necessary to supply the hot utility at the top temperature level. The GCC indicates that we can supply the hot utility over two temperature levels T_{H1} (HP steam) 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: $Q_{Hmin} = H1$ (HP steam) + $H2$ (LP steam). Similarly, $Q_{Cmin} = C1$ (Refrigerant) + $C2$ (CW). The points T_{H2} and T_{C2} where the $H2$ and $C2$ levels touch the grand composite curve are called the “Utility Pinches.” The shaded green pockets represent the process-to-process heat exchange.

In summary, the grand composite curve 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.

5. Estimation of Minimum Energy Cost Targets

Once the DT_{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 QH_{min} and QC_{min} 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

6. Estimation of Heat Exchanger Network (HEN) Capital Cost Targets

The capital cost of a heat exchanger network is dependent upon three factors:

1. the number of exchangers,
2. the overall network area,
3. the distribution of area between the exchangers

Pinch analysis enables targets for the overall heat transfer area and minimum number of units of a heat exchanger network (HEN) to be predicted prior to detailed design. It is assumed that the area is evenly distributed between the units. The area distribution cannot be predicted ahead of design.

- **AREA TARGETING:** The calculation of surface area for a single counter-current heat exchanger requires the knowledge of the temperatures of streams in and out (T_{LM} i.e. Log Mean Temperature Difference or LMTD), overall heat transfer coefficient (U-value), and total heat transferred (Q). The area is given by the relation

$$\text{Area} = Q / [U \times T_{LM}]$$

The composite curves can be divided into a set of adjoining enthalpy intervals such that within each interval, the hot and cold composite curves do not change slope. Here the heat exchange is assumed to be "vertical" (pure counter-current heat exchange). The hot streams in any enthalpy interval, at any point, exchanges heat with the cold streams at the temperature vertically below it. The total area of the HEN (A_{min}) is given by the formula in Figure 8, where i denotes the i th enthalpy and interval j denotes the j th stream and T_{LM} denotes LMTD in the i th interval.

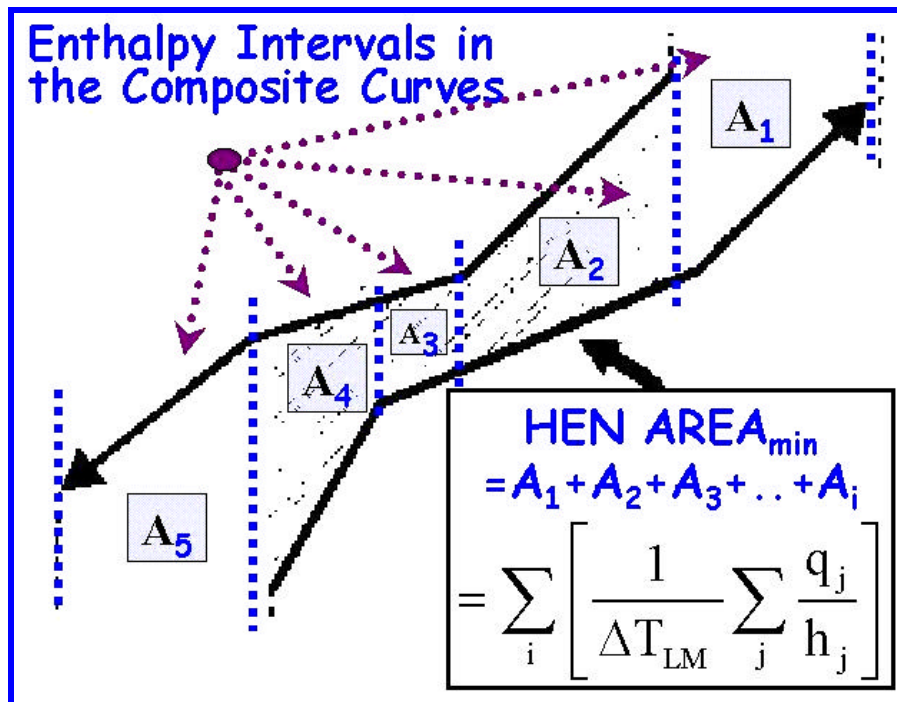


Figure 8: HEN AREA_{min} Estimation from Composite Curves

The actual HEN total area required is generally within 10% of the area target as calculated above. With inclusion of temperature correction factors area targeting can be extended to non counter-current heat exchange as well.

- 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 HEN 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.

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

Where :

N_h = Number of hot streams

N_c = Number of cold streams

N_u = Number of utility streams

AP / BP : Above / Below Pinch

- 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

$$\text{Exchanger cost } (\$) = a + b (\text{Area})^c$$

For the Exchanger Cost Equation shown above, typical values for a carbon steel shell and tube exchanger would be $a = 16,000$, $b = 3,200$, and $c = 0.7$. The installed cost can be considered to be 3.5 times the purchased cost given by the Exchanger Cost Equation.

7. Estimation of Optimum DT_{min} Value by Energy-Capital Trade Off

To arrive at an optimum DT_{min} value, the total annual cost (the sum of total annual energy and capital cost) is plotted at varying DT_{min} values (Figure 7). Three key observations can be made from Figure 9:

- An increase in DT_{min} values result in higher energy costs and lower capital costs.
- A decrease in DT_{min} values result in lower energy costs and higher capital costs.
- An optimum DT_{min} 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 $DT_{min,OPTIMUM}$ for the process.

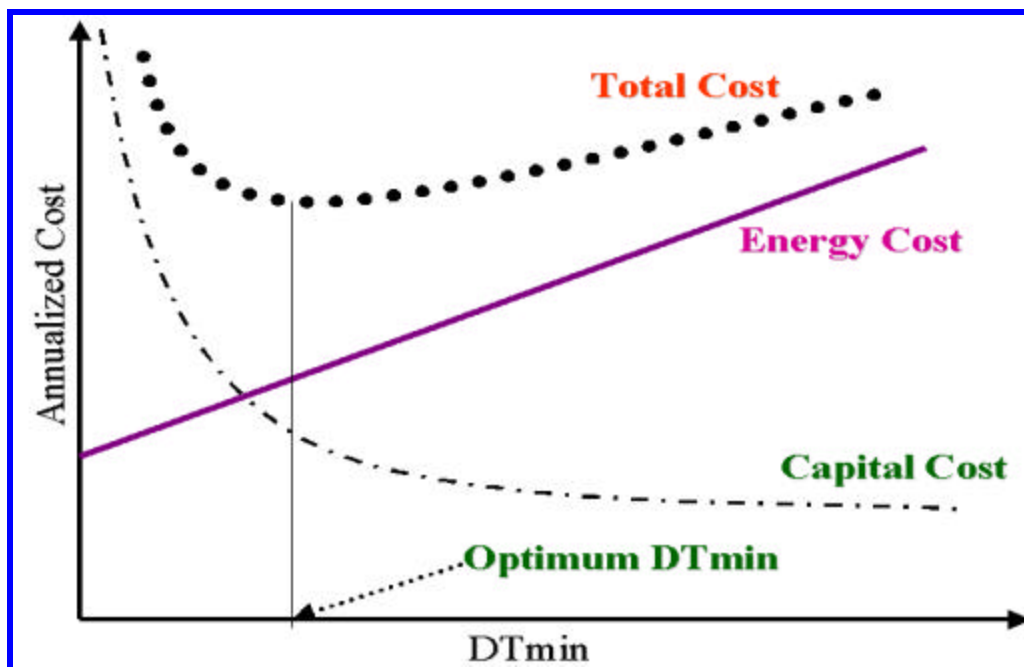


Figure 9: Energy-Capital Cost Trade Off (Optimum DT_{min})

8. Estimation of Practical Targets for HEN Design

The heat exchanger network designed on the basis of the estimated optimum DT_{min} value is not always the most appropriate design. A very small DT_{min} value, perhaps 8°C , can lead to a very complicated network design with a large total area due to low driving forces. The designer, in practice, selects a higher value (15°C) and calculates the marginal increases in utility duties and area requirements. If the marginal cost increase is small, the higher value of

DT_{min} is selected as the practical pinch point for the HEN design.

Recognizing the significance of the pinch temperature allows energy targets to be realized by design of appropriate heat recovery network.

So what is the significance of the pinch temperature?

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. Hence, for an optimum design, no heat should be transferred across the pinch. This is known as the key concept in Pinch Technology.

To summarize, 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.

Plus/Minus Principle: 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 reactor conversions, distillation column 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 as discussed above, 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 provide us the following guidelines:

- Increase (+) in hot stream duty above the pinch.
- Decrease (-) in cold stream duty above the pinch.

This will result in a reduced hot utility target, and any

- Decrease (-) in hot stream duty below the pinch.
- Increase (+) in cold stream duty below the pinch

will result in a reduced cold utility target.

These simple guidelines provide a definite reference for the adjustment of single heat duties such as vaporization of a recycle, pump-around condensing duty, and others. 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.

The process changes that can help achieve such stream shifts essentially involve changes in following operating parameters:

- reactor pressure/temperatures
- distillation column temperatures, reflux ratios, feed conditions, pump around conditions, intermediate condensers
- evaporator pressures
- storage vessel temperatures

For example, if the pressure for a feed vaporizer is lowered, vaporization duty can shift from above to below the pinch. This leads to reduction in both hot and cold utilities.

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 distillation columns, evaporators, heat engines, furnaces, and heat pumps. For example, a single-effect evaporator having equal vaporization and condensation loads, should be placed such that both loads balance each other and the evaporator can be operated without any utility costs. This means that appropriate placement of the evaporator is on either side of the pinch and not across the pinch.

In addition to the above pinch rules and principles, a large number of factors must also be considered during the design of heat recovery networks. 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.

With a little practice, the above principles enable the designer to quickly pan through 40-50 possible modifications and choose 3 or 4 that will lead to the best overall cost effects.

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.

9. Design of Heat Exchanger Network

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: (1) 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 (2) it allows the designer to choose between match options.

In effect, the design of network 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. As 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**' (Figure 10).

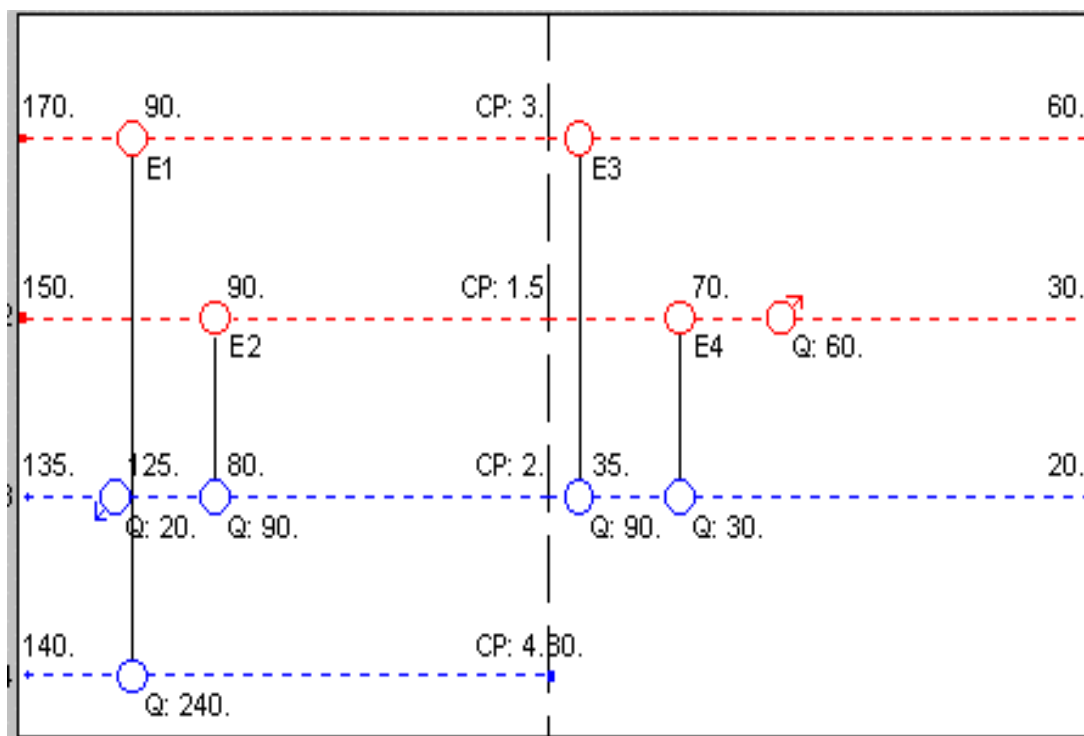


Figure 10: Typical Grid Diagram

All the cold (blue lines) and hot (red line) 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 "CP Inequality Rule", "Stream Splitting", "Driving Force Plot" and "Remaining Problem Analysis". The stepwise procedure can be understood better with the help of an example problem (Link-5).

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. For more details on HEN Design check the Link –6 at the end of the article.

Benefits & Applications of Pinch Technology

One of the main advantages of Pinch Technology over conventional design methods is the ability to set energy and capital cost targets for an individual process or for an entire production site ahead of design. Therefore, in advance of identifying any projects, we know the scope for energy savings and investment requirements.

General Process Improvements

In addition to energy conservation studies, Pinch Technology enables process engineers to achieve the following general process improvements:

- **Update or Modify Process Flow Diagrams (PFDs):** Pinch quantifies the savings available by changing the process itself. It shows where process changes reduce the overall energy target, not just local energy consumption.
- **Conduct Process Simulation Studies:** Pinch replaces the old energy studies with information that can be easily updated using simulation. Such simulation studies can help avoid unnecessary capital costs by identifying energy savings with a smaller investment before the projects are implemented.
- **Set Practical Targets:** By taking into account practical constraints (difficult fluids, layout, safety, etc.), theoretical targets are modified so that they can be realistically achieved. Comparing practical with theoretical targets quantifies opportunities "lost" by constraints - a vital insight for long-term development.
- **Debottlenecking:** Pinch Analysis, when specifically applied to debottlenecking studies, can lead to the following benefits compared to a conventional revamp:
 - Reduction in capital costs
 - Decrease in specific energy demand giving a more competitive production facility

For example, debottlenecking of distillation columns by Column Targeting can be used to identify less expensive alternatives to column retraying or installation of a new column.

- **Determine Opportunities for Combined Heat and Power (CHP) Generation:** A well-designed CHP system significantly reduces power costs. Pinch shows the best type of CHP system that matches the inherent thermodynamic opportunities on the site. Unnecessary investments and operating costs can be avoided by sizing plants to supply energy that takes heat recovery into consideration. Heat recovery should be optimized by Pinch Analysis before specifying CHP systems.
- **Decide what to do with low-grade waste heat:** Pinch shows, which waste heat streams, can be recovered and lends insight into the most effective means of recovery.

Industrial Applications

The application of Pinch Technology has resulted in significant improvements in the energy and capital efficiency of industrial facilities worldwide. It has been successfully applied in many different industries from petroleum and base chemicals to food and paper. Both continuous and batch processes have been successfully analyzed on an individual unit and site-wide basis. Pinch technology has been extensively used to capitalize on the mistakes of the past. It identifies the existence of built-in spare heat transfer areas and presents the designer with opportunities for cheap retrofits. In case of the design of new plants, Pinch Analysis has played a very important role and minimized capital costs.

A Case Study: When Pennzoil was adding a residual catalytic cracking (RCC) unit, the gas plant associated with the RCC and an alkylation unit at its Atlas Refining facility in Shreveport, energy efficiency was one of their major considerations in engineering the refinery expansion. Electric Power Research Institute (EPRI) and Pennzoil's energy provider, SWEPCO, used pinch technology to carry out an optimization study of the new units and the utility systems that serve them rather than simply incorporating standard process packages provided by licensors. The pinch study identified opportunities for saving up to 23.7% of the process heating through improved heat integration. Net savings for Pennzoil were estimated at \$13.7 million over 10 years.

The Future Outlook

The development of Pinch Technology started in the late 1970s and still continues. Besides applications in energy conservation, new developments in Pinch Analysis are being made in the areas of water use minimization, waste minimization, hydrogen management, plastics manufacturing, and others. A few of key areas of research are mentioned described below.

- **Regional Energy Analysis**

By examining the net energy demands of different companies combined, the potential for sharing heat between companies can be identified. These analyses can lend insight into the amount and temperature of waste heat in an industrial area that is available for export. Depending on the temperature of this waste heat, it can be used for district heating or power generation.

- **Total Site Analysis**

Typically, refinery and petrochemical processes operate as parts of large sites or factories. These sites have several processes serviced by a centralized utility system. There is both consumption and recovery of process steam via the steam mains. The site imports or exports power to balance the on-site power generation. The process stream heating and cooling demands, and co-generation potential, dictate the site-wide fuel demand via the utility system.

In such large sites, usually the individual production processes and the central services are controlled by different departments which operate independently. The site infrastructure usually suffers from inadequate integration. To improve integration, a simultaneous approach to consider individual process issues alongside sitewide utility planning is necessary. Similar to a single process, a Total Site Analysis using Pinch Technology can be used to calculate energy targets for the entire site. For example, how much low pressure, medium pressure, and high pressure steam should the site be using? How much steam can be raised and how much power it can generate? This also helps to identify key process changes that will lower the overall site utility consumption.

- **Network Pinch**

When optimizing energy consumption in an existing industrial process, a number of practical constraints must be recognized. Traditional Pinch Technology focuses on new network designs. Network Pinch addresses the additional constraints in problems associated with existing facilities. This analysis identifies the heat exchanger forming the bottleneck to increasing heat recovery. Then provides a systematic approach to remove this bottleneck. This step-by-step method provides an approach for implementing energy savings in a series of consecutive projects.

- **Top Level Analysis**

Gathering the required data in industrial areas is not an easy task. With a Top Level Analysis, only efficiencies and constraints of the utility system are used to determine which utility is worth saving. Data can be gathered from those processes or units that use these utilities. A pinch analysis can then be performed on this equipment.

- **Optimization of Combined Heat and Power**

Typically, multiple steam turbines are used in complex steam systems. CHP optimization gives a way to determine the load distribution in a network of turbines with a given total load.

- **Water Pinch**

In view of rising fresh water costs and more stringent discharge regulations, Pinch Analysis is helping companies to systematically minimize freshwater and wastewater volumes. Water Pinch is a systematic technique for analyzing water networks and reducing water costs for processes. It uses advanced algorithms to identify and optimize the best water reuse, regeneration, and effluent treatment opportunities. It has also helped to reduce losses of both feedstock and valuable products in effluent streams.

- **Hydrogen Pinch**

The Pinch Technology approach applied to hydrogen management is called Hydrogen Pinch. Hydrogen Pinch enables a designer to set targets for the minimum hydrogen plant production and/or imports without the need for any process design. Methods have also been developed for the design of hydrogen distribution networks in order to achieve the targets. Hydrogen Pinch also lends insight into the effective use of hydrogen purification units.

Conclusions

With all of the tools that pinch analysis provides, one of the most important challenges before process engineers is to properly integrate pinch tools into the conceptual process design phase. Decisions made in this phase of planning affect the entire life cycle of a process facility. Using pinch technology tools and understanding the process does not ensure the desired results. These tools must be applied at the right point in the process design phase. Just as it would be incorrect to conduct a Pinch Analysis after completion of the process design phase, wherein critical process parameters have been fixed, it is just as incorrect to conduct a Pinch Analysis without direct interaction with the process specialists and downstream engineering disciplines. **It is Pinch Technology's role to identify "what might be". However, input from other engineering disciplines ultimately determines "what can be".**

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- **Web Links**

- LINK 1: [Software Demos](#)
- LINK 2: [More on DATA EXTRACTION PRINCIPLES](#)
- LINK 3: [More on Typical DTmin values](#)
- LINK 4: [More on PROBLEM TABLE ALGORITHM](#)
- LINK 5: [Sample Problem](#)
- LINK 6: [More on HEAT EXCHANGER NETWORK DESIGN](#)