CHAPTER II

BACKGROUND AND LITERATURE SURVEY

2.1 Pinch Technology

Linhoff and Vredeveld introduced the term of " Pinch Technology" which was based on thermodynamic method that can guarantee minimum energy level in design of heat exchanger network. Over the last two decades, as an unconventional development in process design and energy conservation has emerged. The term of Pinch Technology is often used to represent the application of the tools and algorithms of Pinch Technology for studying industrial process. Development of rigorous commercial software programs like PinchExpressTM ,Super targetTM, and Aspen Pinch TM have been proved to be very useful in pinch analysis of complex industrial process with speed and efficiency.

Not only pinch technology can be applied for energy saving but optimization technique is also useful. Pinch technology is a practical ways and uses table algorithm to explain for retrofit but optimization technique uses mathematical model to explain as shown in Figure 2.1 (Bagajewicz,M)

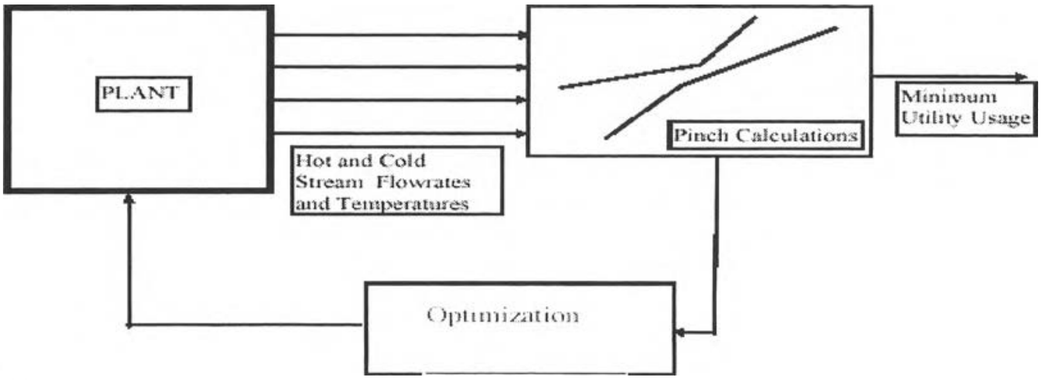


Figure 2.1 Retrofit Horizons(Optimization Based Procedure).

Objectives of Pinch Analysis

Cost and energy savings are the objectives of Pinch by process integration to maximize process to process heat recovery and minimize the external utility load.

Pinch analysis is one choice for doing process integration to save cost of production such as capital cost , and operating cost. The procedure first predicts, the minimum requirement of external energy , network area, and the number of units for a given process at the pinch point ahead of design. Next a heat exchanger network is designed to satisfy these targets. Finally the network is optimized by comparing energy and capital costs of the network so that the total annual cost is minimized.

Basic of Pinch analysis

Based on thermodynamic law, Pinch technology is used to represent a chemical industry process as either utility usages in process or other chemical equipments especially in heat exchanger network. Because of temperature difference between each stream, it can lead to get benefit from thermodynamic method and pinch analysis which is practically useful for chemical processes. There are two types of streams in process; hot and cold streams. Both streams can exchange heat together by using thermodynamic law which states that hot stream can not be cooled below temperature of cold stream and also cold stream can not be heated above hot stream temperature. Normally ,some streams have excess heat so that they can share to other stream. First of all, it needs to set target temperature in each stream in order to design heat exchanging network. It can tell that how much heat must be supplied or which stream should be matched.

In practice the hot stream can only be cooled with a temperature difference defined by the 'temperature approach' of the heat exchanger. The temperature approach is the minimum allowable temperature difference (ΔT min) in the stream profiles, for the heat exchanger unit. The temperature level at ΔT min 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 .

2.1.1 Steps of Pinch Analysis

To do pinch analysis , there are several steps, shown in Figure 2.2 but it should be noted that these steps are not necessarily performed on a once-through basis, independent of one another. Additional activities to get more correct data such as resimulation and data modification occur as the analysis proceed and some iterations between the various steps are always required.

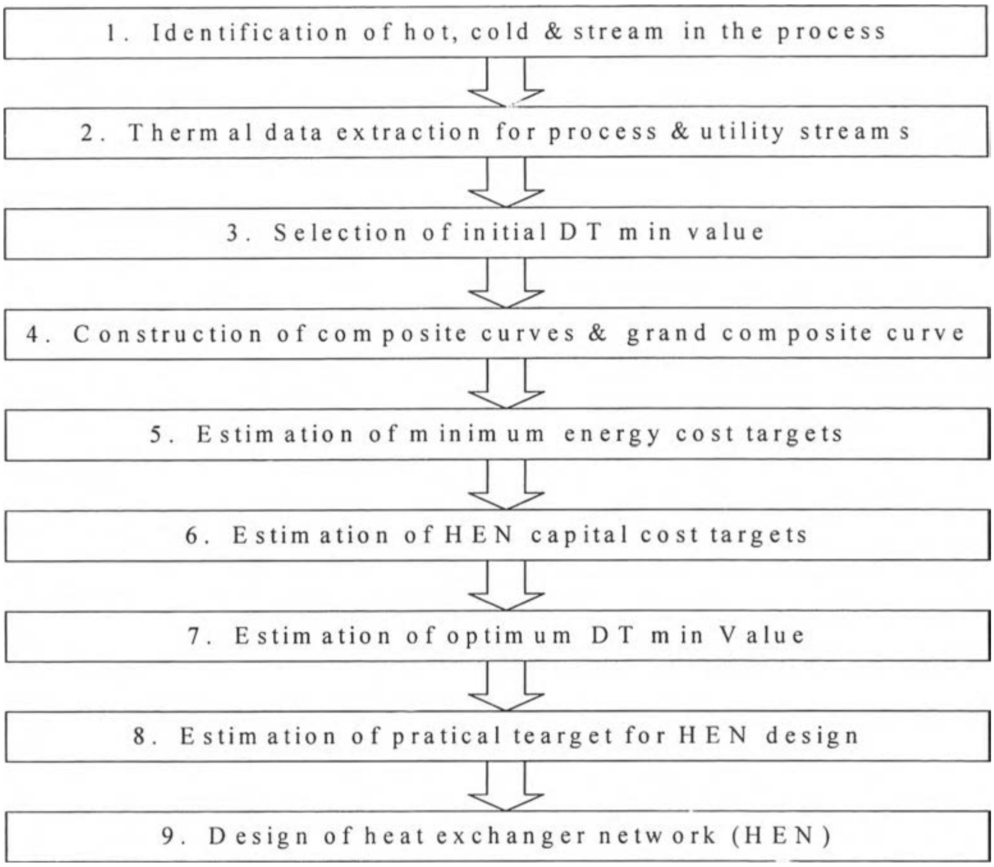


Figure 2.2 Step of pinch analysis (Linnhoff, B. and Hindmarsh, E., 1983).

2.1.1.1 Identification of the Hot , Cold and Utility Streams in The Process

Before doing anything, it is necessary to identify hot streams, cold streams or utility streams.

Hot stream is a stream needed to decrease temperature by exchanging with either cold stream or cold utility. For example, the temperature of hot product is reduced before loading to the storage.

Cold stream is a stream needed to increase temperature by exchanging with either hot stream or hot utility. For example, the temperature of feed stream is increased before entering to the reactor.

Utility stream is a stream which can exchange heat with hot or cold process streams when heat recovery between cold and hot process streams is not enough or not economic. It is able to use utility streams instead of heat exchanging streams. For instance, hot streams are steam, hot water, flue gas, etc. cold streams are cooling water , air ,refrigerant , etc.

Streams used in pinch technology must be carefully considered since some streams can not be used due to improper condition. For example, when a gas stream is compressed the stream temperature rises because of the conversion of mechanical energy into heat by any fluid to fluid heat exchange. Hence such a stream may not be available to take part in any heat exchange. As considering in pinch , some stream might or might not be used in process stream.

2.1.1.2 Thermal Data Extraction for Process &Utility Streams

Hot streams are referred to streams required cooling i.e. the supply temperature (TS) is higher than the target temperature (TT). While cold streams are referred to those required heating. i.e. the target temperature is higher than the supply . Therefore , in thermodynamic law , heat will be transferred from hot stream to cold stream, as shown in this below equation

$$\Delta H = m\,Cp\,(TS - TT)$$

where

ΔH = enthalpy change

m = mass flow rate

Cp = specific heat

TS = supply temperature

TT = target temperature

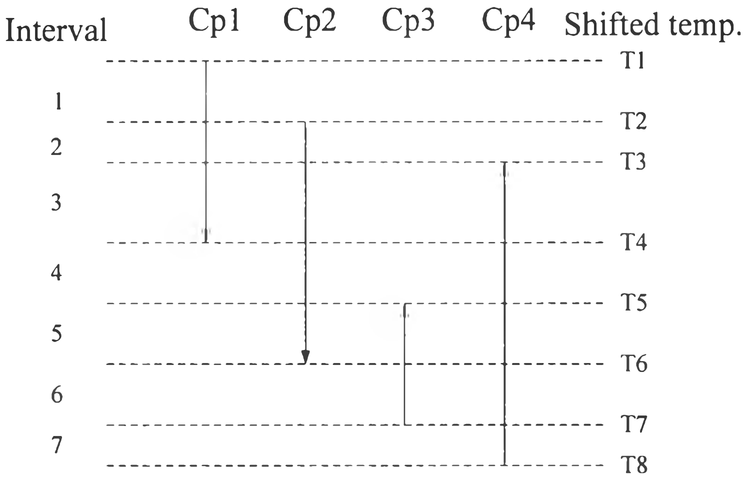


Figure 2.3 Set up intervals.

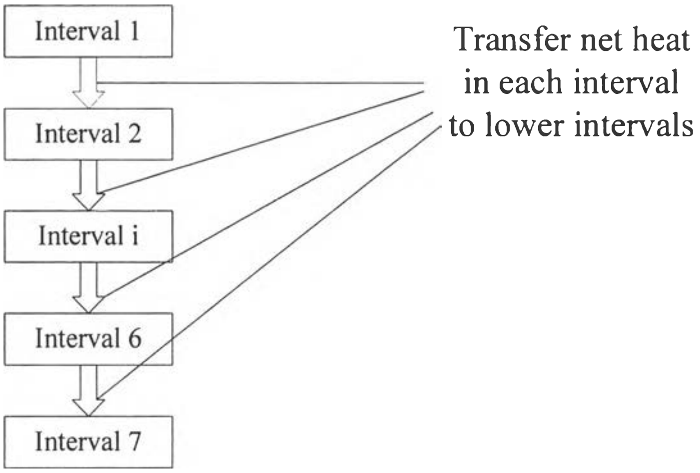


Figure 2.4 Cascade heat surpluses(Linnhoff and Hindmarsh, 1983).

Figures 2.3 and 2.4 show how to consider heat transferring when performing pinch analysis. It must be settled in intervals first and then go to find energy flow (surpluses) which flow from one interval to other interval.

The stream data and their potential effecting on the conclusions of pinch analysis should be considered during all steps of the analysis. Any erroneous or incorrect data can lead to false conclusion. In order to avoid mistakes, the data extraction is based on certain qualified principles.

2.1.1.3 Selection of Initial ΔTmin Value

Based on second law of thermodynamics that prohibits any temperature crossover between the hot and the cold streams, 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 (ΔTmin). This ΔTmin value represents the bottle neck of the heat recovery.

ΔTmin is selected by doing iteration for varying values of ΔTmin and then it can lead to optimum operating cost and capital cost as shown in Figure 2.5. After ΔT is fixed further step can be performed. Low ΔT min will give low driving force so the area of exchanger must be large ,operating cost will be low but capital cost will be high . In the other hand, if we choose high ΔTmin, it will give high driving force, and low area of exchanger. Operating cost will be high while, capital cost will be low. Eventually, ΔT min will be chosen at optimum point at overall cost (capital cost+operating cost)

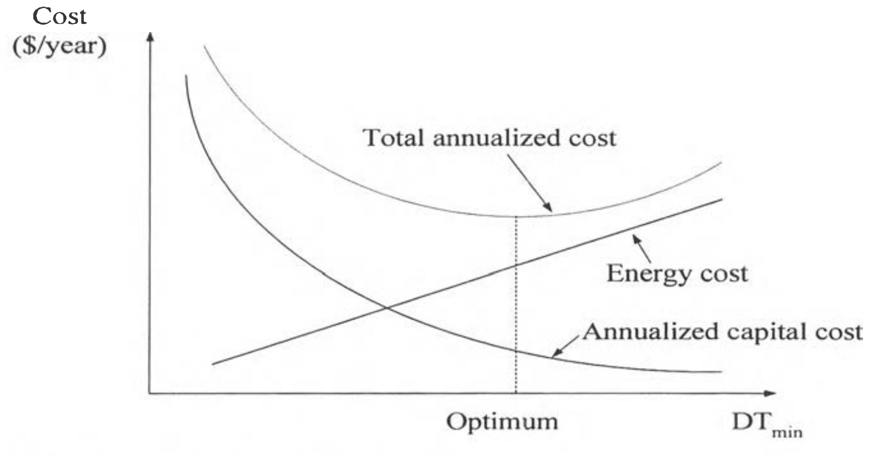


Figure 2.5 Cost trade-off of heat recovery system.

Heat transfer coefficient (U) and the geometry of the heat exchanger can determine the value of ΔTmin .In a network design , the type of heat exchanger used at the pinch point will be determined as the practical ΔT min for the network. For example, an initial selection for the ΔTmin 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 to Q,U,A and LMTD is shown below

$$Q = UA(LMTD)$$

Where

Q = Transferred heat
U = Overall heat transfer coefficient
A = Area of exchanger
LMTD = Log mean temperature difference

For single heat exchanger , selection of ΔTmin is vital in the design of a heat exchanger network. An initial ΔTmin value is chosen and pinch analysis is carried out.

2.1.1.4 Construction of Composite Curves and Grand Composite Curves

Composite Curves (CCs)

This curves showed temperature and enthalpy plot between hot and cold streams (hot composite curve and cold composite curve). In each stream , stream enthalpy value is calculated by using thermal properties themselves and composite curves is consequently plotted. In this curve there is one point which has minimum temperature difference (ΔT min) between hot composite curve and cold composite curve . It is called pinch point. Increasing ΔTmin value results in shifting the curve horizontally apart in lower process to process heat exchange and high utility requirements. At a particular ΔTmin value , the overlap shows the maximum possible scope for heat recovery within the process. The hot and cold ends overshoot indicates minimum hot utility requirement (Q_H min) and minimum cold utility requirement (Qc min), of the process for the chosen ΔT min

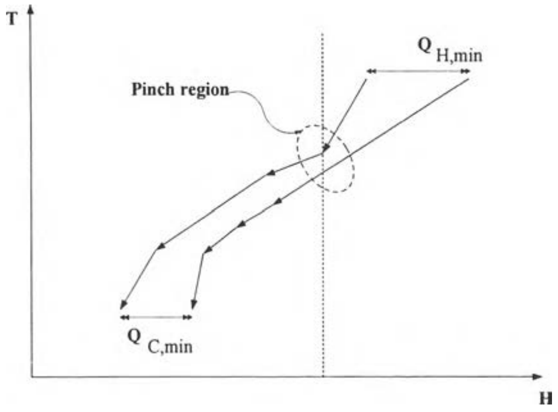


Figure 2.6 Composite curve (Linnhoff *et al.*,1982).

The composite curves provide overall energy target as shown in Figure2.6. Composite curve just show how much energy is needed but do not clearly indicate how much energy must be supplied by different utility levels. The utility mix is determined by the Grand composite curves.

To perform composite curves, it is necessary to adjust temperature for both streams, increasing the cold composite temperature by increasing the value of 1/2ΔT min and decreasing ΔT min with hot composite temperature.

Grand Composite Curve(GCC)

Similar to composite curve, this grand composite curve shows how much utilities needed to supply but this curve can specify which utility are to be used at any temperature level. The objective is to get lowest utility level and minimize the use of the expensive utility levels by maximizing energy recovery. For example , it is not necessary to use high pressure steam in process despite cold steam is enough to exchange heat or it is not necessary to use refrigerant to cool down the stream despite it has enough cooling water .

These curves are developed by Linnhoff & Flower (1978). The method involves shifting hot composite curve down by ΔT min and cold composite curve up by ΔT 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 temperature. The result is scaled based upon process temperature having an allowable temperature approach (ΔTmin). The grand composite curve is generated from enthalpy difference in horizontal of composite curve at different temperature. In GCC, the horizontal distance at the top temperature scale shows the overall hot utility consumption of the process.

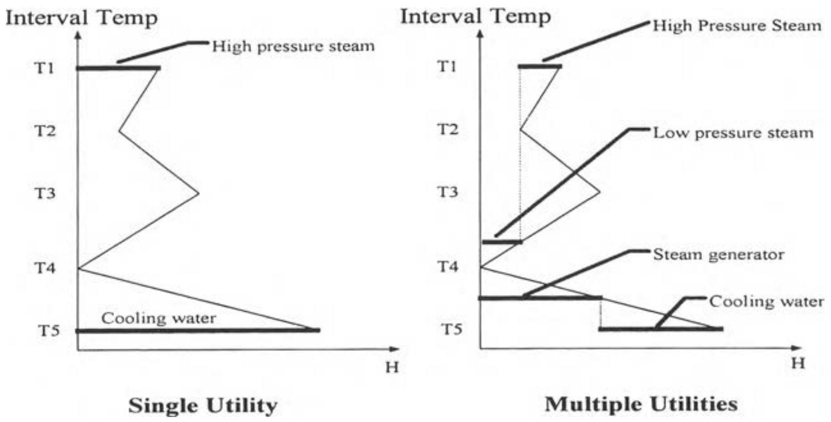


Figure 2.7 Grand composite curve.

The grand composite curve is one of the 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 levels by maximizing the least expensive utility load on the most expensive utility.

2.1.1.5 Estimation of Minimum Energy Cost Targets

After GCC has been provided , the cost of each utility is known, the total energy cost can be calculated using the energy equation given below.

$$\text{Total energy cost} \quad = \quad \sum_{U=1}^{U} Q_U * C_U$$

Where Q_U = Duty of utility U ,kw

C_U = Unit cost of utility U ,\$/kw,yr
U = Total number of utilities used

2.1.1.6 Estimation of Heat Exchanger Network (HEN) and Capital Cost Targets

There are three factors which affect HEN cost

- number of exchangers
- the overall network area
- the distribution of area between the exchangers

A Composite curve gives how much area will be necessarily used. Minimum area requirement can be achieved by vertical heat transfer between hot and cold composites.

$$\text{Area interval} = \sum_{j}^{\text{interval}} (1/\Delta T_{lm}) * \sum_{i}^{\text{stream}} (Qi/Ui)$$

This equation gives the minimum area required for heat recovery network if heat transfer coefficients of all streams are uniform. But it is still acceptable if heat transfer coefficients are not much different with others. However if there are large differences in heat transfer coefficients, criss-cross matching may give better area prediction than vertical heat transfer.

To get easier calculation , it should be divided into each interval and find area of each interval and then integrate areas of each interval to get overall heat exchange area as shown in Figure 2.8 Since the slope of hot and cold composite curves do not change, the hot stream at any enthalpy interval, at any point, exchanges heat with cold stream at the temperature vertically below it. The actual HEN total area is required 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.

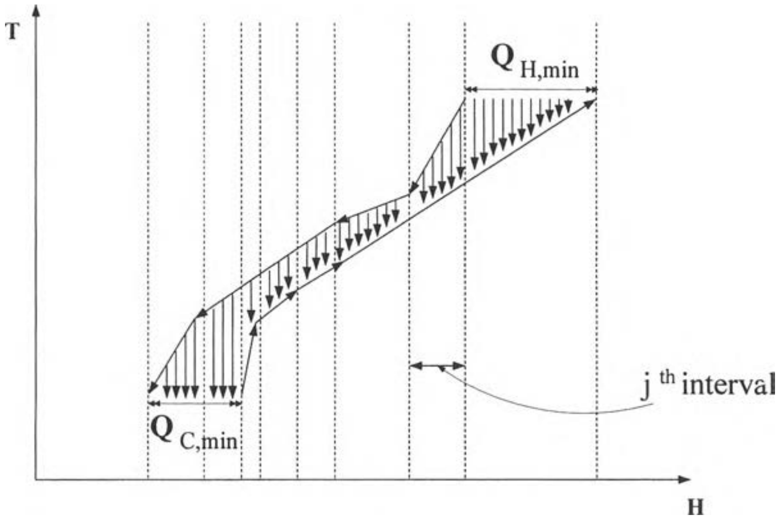


Figure 2.8 General expression for network area target.

Number of Unit Targeting

It is the best if number of unit that will be used is minimum. A formula which will be shown to find minimum number of unit is

$$\text{NminMER} = (\text{Nh}+\text{Nc}+\text{Nu}-1)_{AP} + (\text{Nh}+\text{Nc}+\text{Nu}-1)_{BP}$$

(Linnhoff, B., Polley, G.T., and Sahdev, V.,1988)

Where Nh = Numbers of hot streams

Nc = Number of cold streams

Nu = Number of utility streams

AP = Above Pinch BP = Below Pinch

Hen Total Capital Cost Targeting

Capital cost of single exchanger

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

(Linnhoff, B., Polley, G.T., and Sahdev, V.,1988)

Where a = Installation cost

b = Materials cost

c = Scale factor

Capital cost target of a network

$$\mathrm{Cost}_{network} = N_{min}(a+b(A_{target}/N_{min})^{c})$$

Annualised Capital Cost

Since capital cost is not defined per year so it needs to connect to annualized capital cost as shown below.

Energy cost : \$/year

Capital cost : \$

To combine these costs,capital cost is needed to be 'annualized'

Annualized capital cost = (C.A.F.) × (Capital cost)

C.A.F. = Capital annualized factor

$$\mathrm{C.A.F.} = (I(I+1)^{n}) / (I+1)^{n-1})$$

(Linnhoff, B., Polley, G.T., and Sahdev, V.,1988)

Where I = Interest rate per annum

n = Plant life(year)

2.1.1.7 *Estimation of Optimum ΔTmin Value by Energy-Capital Trade Off*

As mentioned in step 3(Selection of initial ΔTmin value) , Total cost will change if value of ΔTmin is varied. There are three observations if varying ΔTmin is performed.

- Increasing of ΔTmin will result in higher energy costs and lower capital costs
- ΔTmin decreasing will result in lower energy costs and higher capital costs

The best ΔTmin to be used should give lowest total cost (energy cost plus capital cost)

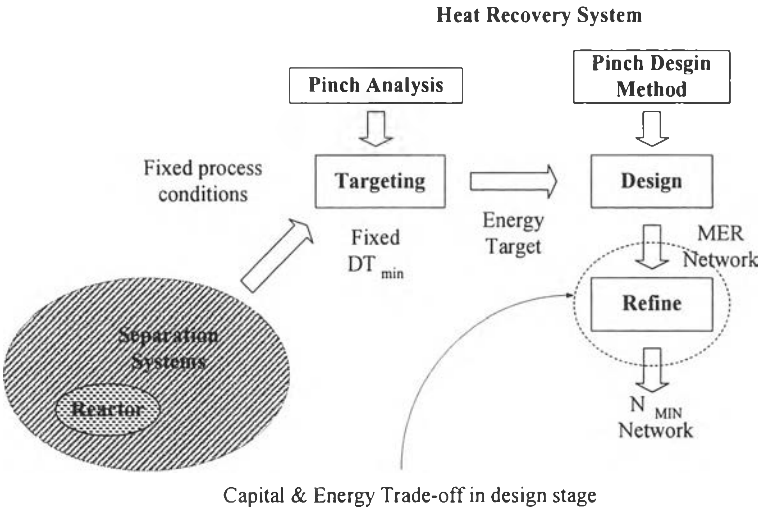


Figure 2.9 Capital & Energy Cost Trade-off.

2.1.1.8 Estimation of Practical Targets for HEN Design

HEN design must be based on ΔTmin selection , it can be any value but if ΔTmin is too small, For example ,6 c°, it will be very complicated to design HEN and also has a very small driving force so it causes high area of exchanger. The designer, in practice , selects a higher ΔT_{min}value (15 c°) and calculates the marginal increase in utility duties and area requirement. If the marginal cost increase is small, the higher value of ΔTmin 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. 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 transfers across the pinch as shown in Figure 2.9

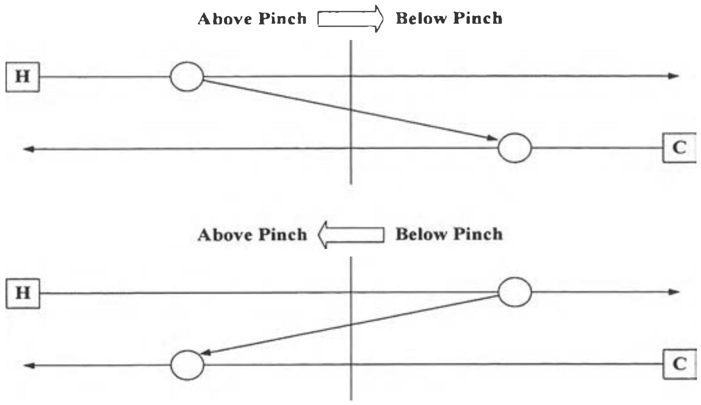


Figure 2.10 Cross pinch on grid diagram.

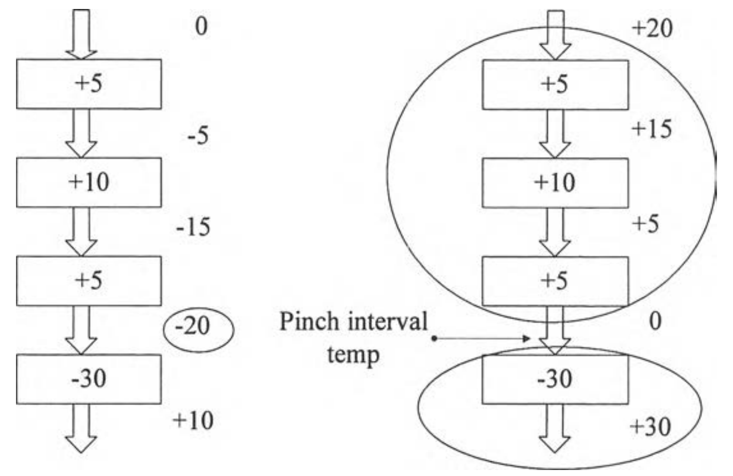
Any violation of the above rules results in higher energy requirements than the minimum energy requirements.

2.1.1.9 Design of Heat Exchanger Network

From targeting stage, it is determined the minimum hot and cold utility requirements of the process at any given minimum temperature approach as energy target.

The network design stage is studied to achieve this energy target. When heat exchanger network design is performed, it needs one diagram which can clearly show how hot and cold streams match.

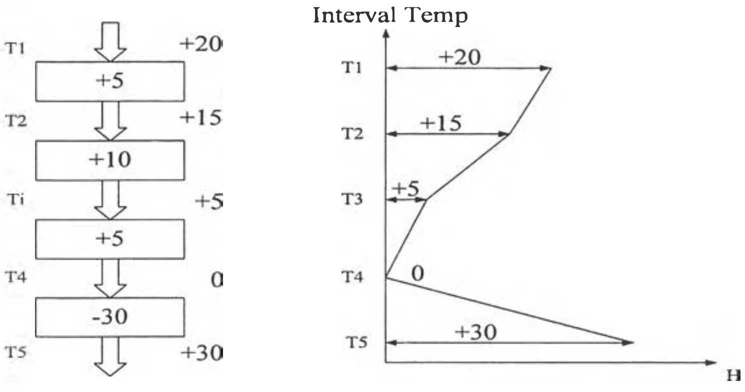
Figures 2.11 and 2.12 will explain step of finding ΔT and go to get grand composite curve, these steps are necessary to do when it will pass to further step.



Find max. absolute energy flow in interval heat transfer.

Add that amount of max. absolute energy flow on the top interval.

Figure 2.11 Determining pinch interval temperature.



Cascade Diagram

Grand Composite Curve (GCC)

Figure 2.12 Plotting grand composite curve(Linnhoff and Hindmarsh, 1983).

Grid diagram

This diagram represents all of stream lines either cold or hot lines, it is divided into two regions, above pinch, and below pinch regions. After ΔTmin has already been provided, The grid diagram is generated with location of pinch, as shown in Figure 2.13 The benefit of grid diagram is to show stream matching and get the best network done in this diagram.

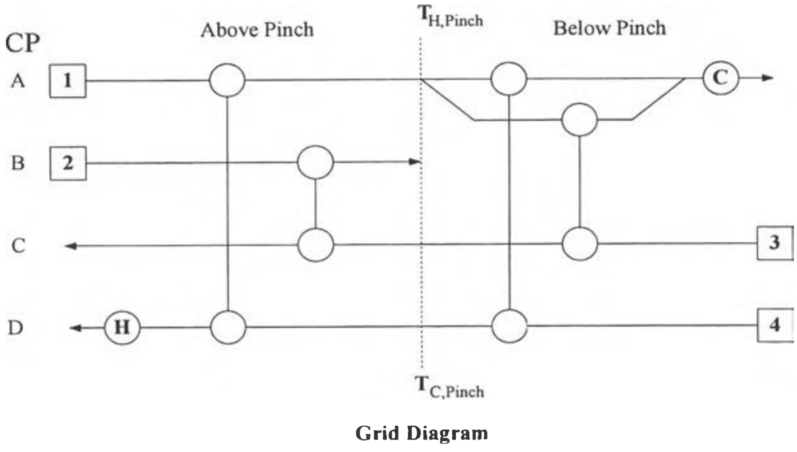


Figure 2.13 Grid diagram (Linnhoff and Hindmarsh, 1983).

When doing heat exchanger network on grid diagram, it should start at pinch point, then extend to each region and finally combine each region to be one network.

Normally, each stream will have different specific heat value(CP) and sometimes amount of hot and cold streams are not equal so that it can lead to get some constraints relating with this condition. The rules of matching are

The feasibility criterion of above pinch region

- Nh must be less than or equal to Nc
- CP of hot stream must be less than CP of cold stream

The feasibility criterion of below pinch region

- Nc must be less than or equal to Nh
- CP of cold stream must be less than CP of hot stream

Where Nh , Nc are number of hot and cold streams
CP are heat capacity

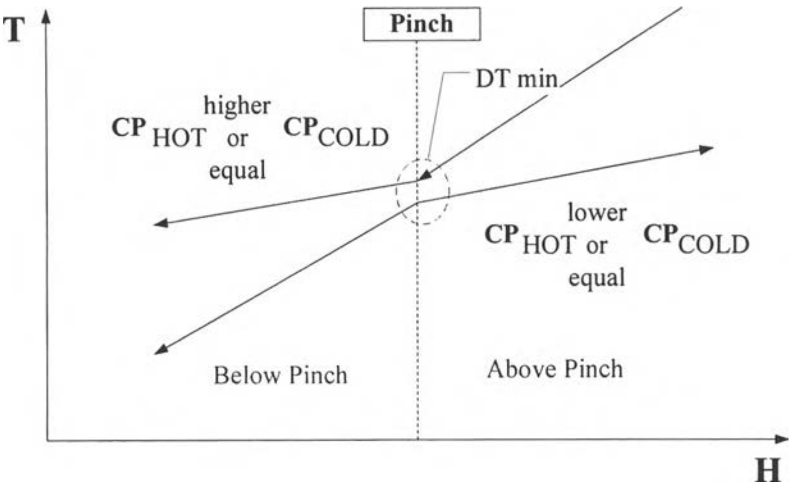
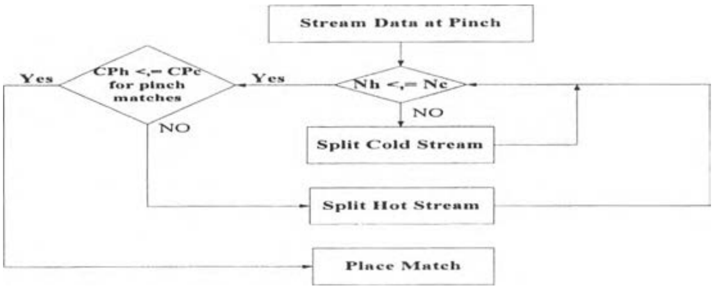


Figure 2.14 General rule for pinch stream matching.

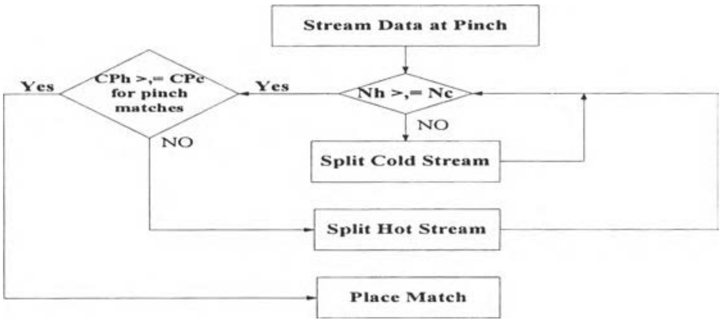
However in some case which does not conform to these rules it can be solved by spitting stream to increase number of streams to reach feasibility. Eventually, it can match with cold stream and get heat exchanger network done.

As described previously, the hot end requires only hot utility so it acts as a heat sink while the cold one requires only cold utility so it acts as a heat source. To achieve this minimum requirement, the design has to obey the pinch principle. The pinch principle comprises of

- There is no heat transfer across the pinch point
- There is no cold utility above the pinch
- There is no hot utility below the pinch



(a)



(b)

Figure 2.15 (a) Stream spitting rules for above pinch.
(b) Stream spitting rules for below pinch.

Figure 2.15 shows conditions whether it need to split stream or not, for example when considering at above pinch if number of cold streams is less than number of hot streams, hot streams must be split or if CP of cold stream is less than hot stream, cold stream can be split to get lower CP value.

2.2 Column Targeting

The goal for column targeting is to reduce utilities cost, improve energy efficiency, reduce capital investment(by improving driving force) and facilitate column debottlenecking. It is very closed to heat integration of the process but now it is just considered only for column. For example, the minimum thermodynamic condition pertains to thermodynamically reversible column operation. In this condition, a distillation column would be operated at minimum reflux, with an infinite number of stages, and with heaters and coolers placed at each stage with appropriate heat loads for the operating and equilibrium lines to coincide. In other word, the reboiling and condensing loads are distributed over the temperature range of operation of the column. The stage-enthalpy(Stage-H) or temperature-enthalpy (T-H) profiles for such a column therefore represent the theoretical minimum heating and cooling requirements in the temperature range of separation. These profiles are called the Column Grand Composite Curves (CGCCs) which is similar to Grand Composite Curve in heat integration of the process.

2.3 Data Reconciliation

Data reconciliation is one technique which uses statistic to adjust accuracy of data. The errors always occur during random measurements. To predict the true value from measurement value, it is necessary to describe the error, X, as shown below

True value = Measured value + X

Ideally, the error is zero so that measured value equals the true value. In practice, this is impossible, but that X can be corrected to be small enough for a reasonably accurate and well-calibrated instrument.

Data reconciliation is fully capable of reconciliation of the measurements with any complete plant model, containing mass, energy componet conservation, vapor-liquid equilibrium, and so on.

2.4 Literature Survey

2.4.1 Applications of Pinch Technology

Pinch technology (PT) was proved to be important for engineers to analyze and design chemical processes (Stankiewicz, 1993) . By allowing engineers to track the heat or pressure flows in all process streams within a plant, PT made it easier to integrate plant design. Rearranging equipments, such as reactors, evaporators, pumps, distillation columns, and separators, can make unit operations more efficient, in energy consumption such as heat exchanger networks. It is available to automate the redesign process and PT is set to move beyond energy, into pressure drop optimization and distillation columns sequencing.

Moreover, the pinch concept is also used to develop a procedure to optimize a licensor's design for complex processes with many utilities and unit operations (Trivedi *et al.*, 1996). The procedure included a method to set the marginal cost for various utility levels. It also illustrates how to use composite and grand composite curves to set the level and load of various. In addition, the method optimizes distillation column using the concepts of column grand composite curves.

In addition to the use of PT as a design tool, it can be combined with exergy analysis to develop a method for process modification (Feng and Zhu, 1997). The graphical representation of pinch analysis combines with the power to identify the cause of thermodynamic imperfection was used to represent the whole system. Omega-H diagram was proposed, energy and exergy balances can be represented in this diagram which helps the process analyst to view the performance and set the target for improvement, modification can be located by viewing the imperfection of the existing process. The same idea was also applied to heat exchanger network analysis (Sorin and Paris, 1997). Heat exchanger network was treated as a single unit operation which simplifies to the graphical representation of exergy and reduces the computational efforts.

Process integration (PI) is a major area in which the pinch analysis is applied (Hallale, 2001). PI is not only the pinch analysis and energy integration but it had been extended its uses to various applications. The four major objectives of PI are 1) efficient use of raw materials 2) energy efficiency 3) emission reduction and 4) process operations. Many applications of pinch technology were discussed. They are used in hydrogen management, total site analysis and integration, heat exchanger networks design and retrofit, column analysis and integration and water management. All of these applications start from generating composite curve, locating pinch point, setting targets and then designing or modifying to achieve the targets.

2.4.2 The Pinch Design Method for New Heat Exchanger Network Design

In pinch analysis, after the designers have set the target for the problem, the next step they have to do is to design a network topology that satisfied the setting target. The first design methodology is called "The pinch design method (PDM)" (Linnhoff and Hindmarsh,1983). The synthesis starts at the pinch and moving away to the remaining parts. The design at the pinch is employed by stream splitting to satisfy pinch principles and the feasibility criteria. The procedure is sped up by tick-off heuristic but this can penalize the energy usage. In the final step, the design topology is trade-off between energy and capital cost by using heat load loop and heat load path.

Linnhoff and Ahmad (1990a) presented a simple methodology for the design of near optimum heat exchanger networks with energy-capital trade-off consideration. The approach is based on setting cost targets, optimizing these target prior to the design by using simple capital cost model which gives the results within 5 percent of the optimum solution. The detailed capital cost models, which consider the difference in heat transfer coefficient, non-linear heat exchanger cost law, non-counter current exchanger, non-uniform material of construction, pressure rating and exchanger type in the network, gives the more accurate results (Ahmad, Linnhoff and Smith, 1990b).

To make a design economically, most of designers are trying to optimize the use of intermediate utilities. In this situation, the utility inches are created in the network problems. The PDM described above is suited for just only one pinch point in the problem. Therefore, the multiple pinch design method was proposed.

Jezowski (1992) reviewed a pinch design method (PDM) for multiple pinch problems. The design is started by defining the inverse pinch point. This point will separate a region between pinches into two sub-regions. The PDM proposed by Linnhoff and Hindmarsh (1983) was used for designing with some guidance. The design is started from both pinches simultaneously. The obtained solutions feature the maximum energy recovery and minimum number of units.

Almost two decades of development, the analysis of the PDM problems was seen by many research groups. Polley and Heggs (1999) showed the problems of the pinch design method (PDM). Firstly, the designs obtained can be non-optimal designs. Secondly, the nature of process streams are not accounted. Thirdly, it does not consider the impact of network on plant piping and process flow. Finally, the software involved usually complicated and they can not give an optimal design. A problem decomposition analysis is used for the design instead of PDM. The design obtained is a network in local which is easily to operate and low cost. The procedure is started from problem simplification, identified the process changes, setting the final problem, decomposition analysis based on flow-sheet and decomposition on a thermal basis.

2.4.3 The Pinch Design Method for Heat Exchanger Network Retrofit

The above discussion is made only to the grass-root design. In practice, there are many petrochemical plants that has been invested for the exchangers. The discussion above is not appropriate for this case, since many of invested heat exchangers have to be eliminated to achieve the energy target. The approach has been developed about the same period as for the grass-root one. The development of method for retrofitting plants based on pinch analysis is discussed below.

Tjoe and Linnhoff (1986) presented a method that used pinch design method for process retrofits. The assumption in this method is a good retrofit that makes the process similar to optimum grass-root design. The first step is to set the target by using area-energy curve. The design was done by assuming that the new area will have the same efficiency as the existing one. The minimum temperature and energy saving are set under a specified payback time or investment. The retrofit is to identify the cross-pinch exchangers and modify them. The method was also applied for ethylene plant retrofit (Linnhoff and Witherell, 1986)

The parameter concerning with the cost of matching was considered in a new approach for heat exchanger network retrofit (Carlsson, Franck and Berntsson, 1993). The criss-cross matching was believed to give a lower cost solution comparing to the vertical matching. In this approach, the cost of match is including the effect of other parameters. The match cost matrices was proposed. The matrices show the type of matching, cost of matching. The designers will select the match and the new matrices will be calculated for the remaining part. The networks cost is the sum of these chosen matches.

Polley and Amidpour (2000) showed the procedure for retrofitting industrial heat exchanger networks. They indicated that the capital investment and payback time are the important economic indicators for process retrofit. The saving-investment plot was used to determine the retrofit target. The retrofit analysis was started by comparing the performance of the existing unit with the ideal relationship via area efficiency. The analysis is based on assumption that any new area has at least the same efficiency as the existing one. In conventional method, the cross-pinch exchangers were identified and then modified them. They also indicated the disadvantages of the existing method. At the same time, they proposed the new procedure by identifying the structure of the revamped units in the first stage and then energy-investment trading-off will be done to size and modify the exchangers.

2.4.4 Process Heat Integration

A process heat integration is concerned about the integration of heat engines, heat pumps, distillation columns with the background processes to achieve as high as benefits over stand alone one. A criteria for placement of heat engines and heat pumps in process networks was first presented by Townsend and Linnhoff (1983a). The criteria proposed is based on the process network pinch. The appropriate placement is the placement at which we can get advantages over the stand alone engines or pumps. For the heat engines, they showed that an appropriate placement is to place them at either above or below pinch but not across process pinch. The situation for heat pumps is opposite. The appropriate placement in this case is to place them across the pinch. They also showed that to get the 100 percent efficiency using the real engines, we have to use a large number of engines connected in series. In addition, they discussed that in practical, we can never achieve a fully appropriate integration due to the heat has to cross the pinch to the ambient. With this development, an application to distillation column was developed in a next few months.

Townsend and Linnhoff (1983b) applied the used of the criterions proposed above for selecting the best practical technology for any design systems. The process source/sink profile was introduced in this procedure. The procedure is based on the pinch analysis. This method can always form a point of reference and take account of practical design constraints. The procedure can be used to evaluate options at the preliminary design stage and to identify the preferred configuration for chemical and other processes involving integrated heat recovery and power generation. The procedure represents a breakthrough in the general area of process synthesis that takes into account the fundamental importance of the heat recovery pinch.

As mentioned before, the heat engine placement was lead to the development of a criterion to place distillation columns into process streams. The discussion was first given by Linnhoff, Dunford and Smith (1983). They discussed about the placement of columns and got the interesting conclusions. First, if the good integration between columns and process is achieved, the columns can be run with free of utility charges. Second, they found that the conventional column integration methods, e.g., multiple effect columns, can prevent the good integration. They showed that the good integration is obtained by placing column in one side of pinch, i.e. not go across the pinch and either the re-boiler or condenser being integrated with the process. If these criteria can be met, energy cost of distillation column can effectively be zero.

The development of an approach for shaft-work targeting directly from process data using pinch analysis (PA) was important in designing low-temperature process (Linnhoff and Dhole, 1992). The approach bypasses the design of both heat exchanger network (HEN) and refrigeration system. The combination of PA and exergy concepts was used in developing the method. Comparison with the existing method, in which shaft-work is determined from the refrigeration load, the proposed approach is simpler. It provides a strong tool for understanding and assisting the designer to find the best HEN and refrigeration system simultaneously. An ethylene process design study was chosen for illustrated the approach.

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