KLM Technology Group Practical Engineering Guidelines for Processing Plant Solutions	KLM Technology Group ENGINEERING SOLUTIONS www.klmtechgroup.com	Page : 1 of 75 Rev: 01 Rev 01 - Feb 2020
KLM Technology Group P. O. Box 281 Bandar Johor Bahru, 80000 Johor Bahru, Johor, West Malaysia.	**Kolmetz Handbook Of Process Equipment Design** **PROCESS INTEGRATION WITH PINCH ANALYSIS** **(ENGINEERING DESIGN GUIDELINES)**	Co Author Rev 01: Apriliana Dwijayanti Editor / Author: Karl Kolmetz

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INTRODUCTION

Scope

Process integration represents an important branch of process engineering initiated in the late 1970's. It refers to the system-oriented, thermodynamics-based, integrated approaches to the analysis, synthesis and retrofit of process plants. The goals of process integration are to integrate the use of materials and energy, and to minimize the generation of emissions and wastes.

Process integration techniques based on pinch technology represent a powerful way to optimize process designs, yielding results superior to those achievable using conventional methods. Pinch technology permit the design engineer to track the energy flows in a manufacturing process more clearly, modify the process to reduce energy consumption and enables the design of an optimum interface between the process and the utility systems.

An important part of pinch analysis is the establishment of minimum achievable consumption targets for the energy, water and/or hydrogen required to operate the process. From representative heat and mass balance for a process, we create a model representing the most important energy and/or material flows.

Process-integration technology is just good process design, and every process engineer should understand and know how to use these tools. This guideline will introduce the fundamental concepts that are used by designers to make decisions about system design of Pinch Integration.

Process Integration

Integration means combining Needs/Tasks of “opposite” kinds so that Savings (or Synergies) can be obtained. Process integration (PI) is an efficient approach that allows industries to increase their profitability through reductions in energy, water and raw materials consumption, reductions in greenhouse gas (GHG) emissions, and in waste generation.

It may be applied to a simple heat exchanger that recovers heat from a process product stream, to waste-heat recovery from a gas turbine, to the optimal scheduling of reactor usage, to the integration of a number of production units in an oil refinery, or to the complete integration of an industrial complex. It is now an integral part of the overall strategy for process development and design, often known as process synthesis, and the optimization of existing plants. The overall design process is effectively represented by the onion diagram, Figure 1.

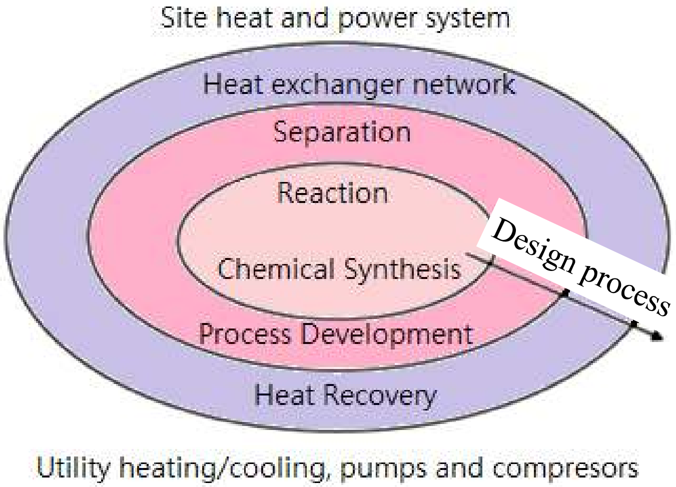


Figure 1: The onion diagram for process synthesis

Examples of such Integration in the Process Industries:

1. *Heat* Integration
   - Cooling and Condensation integrated with Heating & Evaporation
   - Identify near-optimal Level of Heat Recovery
   - Design the corresponding Heat Exchanger Network
2. *Power* Integration
   - Expansion integrated with Compression
   - Same Shaft or combined in “Compander”
3. *Chemical Integration*
   - Byproducts from one Plant used as Raw Materials in other Plants
   - The Idea of materials integration is used in Industrial “Clusters”
4. *Equipment Integration*
   - Multiple Phenomena (Reaction, Separation, Heat Transfer) are integrated in the same piece of Equipment (Process Intensification)

PI techniques may be applied to address the following industrial issues:

1. Energy saving, and GHG emission reduction
2. Debottlenecking of the critical areas in a given process
3. Optimization of batch processes
4. Optimization of hydrogen use
5. Reactor design and operation improvements
6. Minimization of water use and wastewater production
7. Optimization of separation sequences
8. Waste minimization
9. Utility system optimization
10. Investment cost reduction

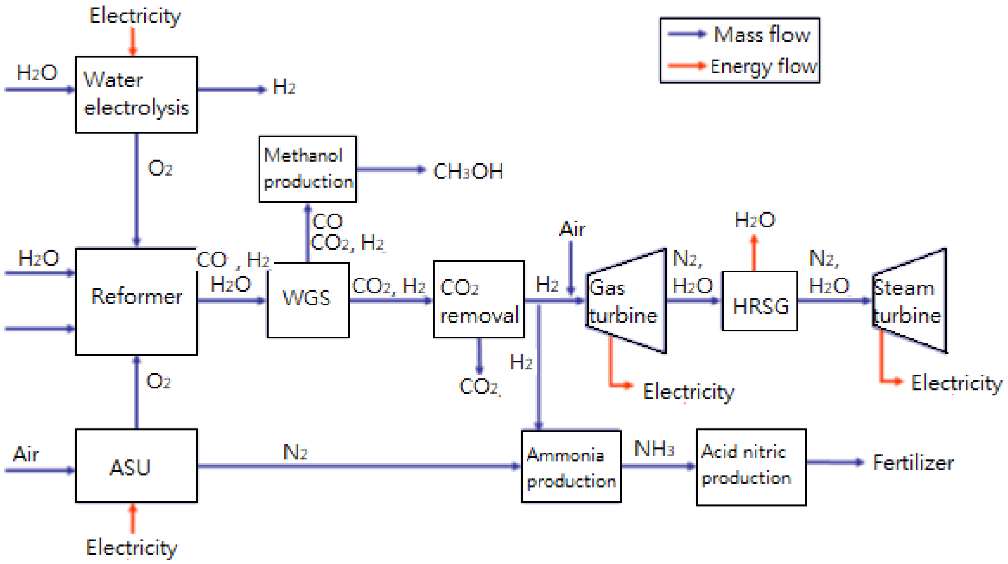
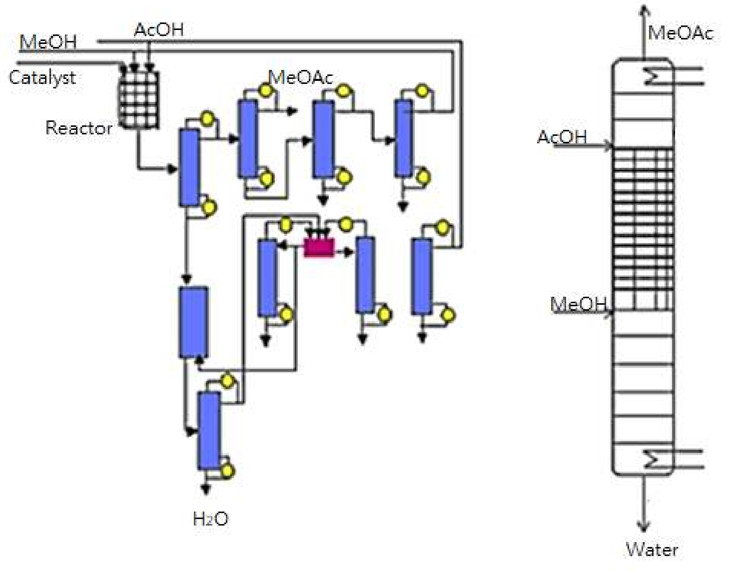


Figure 2: Chemical Integration in an Industrial Cluster (Kaggerud et al, 2006)



Conventional Distillation

Reactive Distillation

Figure 3: Equipment Integration of Methyl Acetate (Siirola, 1996)

The goals of process integration are

1) to integrate the use of materials and energy, and
2) to minimize the generation of emissions and wastes.

Process integration is built on three basic concepts:

1. Consider the big picture first by looking at the whole manufacturing process as an integrated system of interconnected processing units as well as process, utility and waste streams.

2. Apply process-engineering principles, such as thermodynamics and mass and energy balances, to key process steps to establish *a priori* the attainable performance targets on the use of materials and energy and the generation of emissions and wastes

3. Finalize the details of process design and retrofit later to realize the established performance targets.

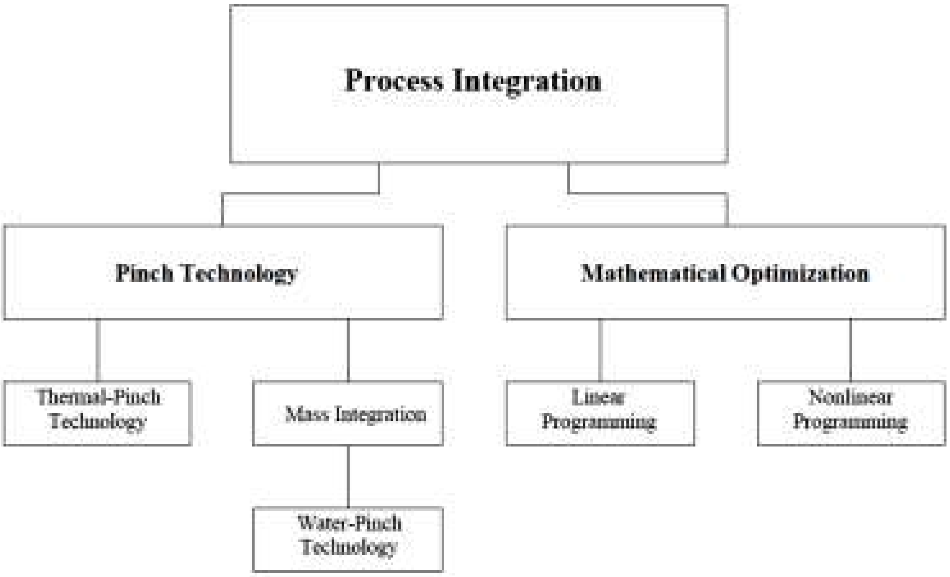


Figure 4 The tools of process integration

Process integration techniques may be applied to address the following industrial issues:

- Energy saving, and GHG emission reduction
- Debottlenecking of the critical areas in a given process
- Optimization of batch processes
- Optimization of hydrogen use
- Reactor design and operation improvements
- Minimization of water use and wastewater production
- Optimization of separation sequences
- Waste minimization
- Utility system optimization
- Investment cost reduction

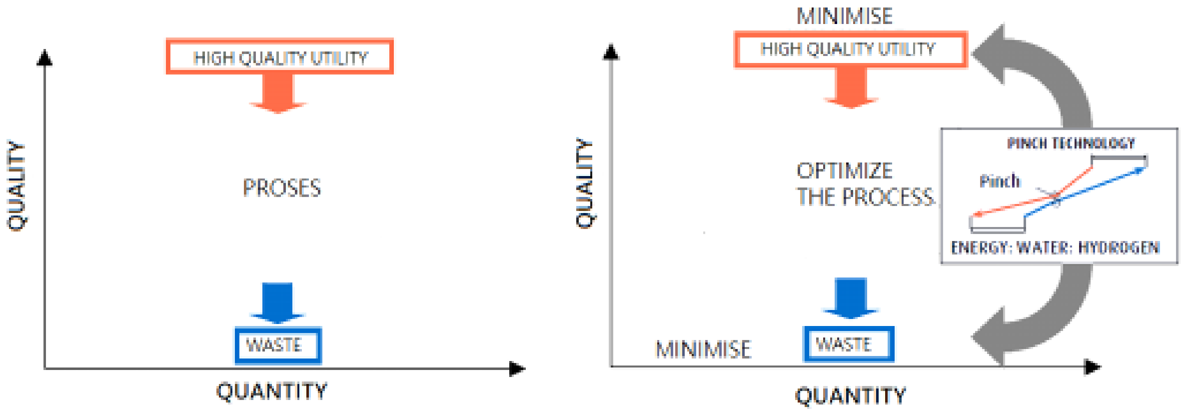
Pinch Technology

Many plants are using high-value utilities in their process and rejecting waste at a lower value. For example the energy, plants may be burning natural gas to provide the process with high temperatures heat, and are rejecting heat at low temperatures to cooling water or air. In the case of water, pure water is fed to the process and reject contaminated wastewater to treatment plants. Pinch analysis now has an established track record in energy saving, water reduction, and hydrogen system optimization.

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. The term ‘Pinch Analysis’ is often used to represent the application of the tools and algorithms of Pinch Technology for studying industrial processes.

Pinch Analysis is a methodology for minimizing energy consumption of processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as "process integration", "heat integration", "energy integration" or "pinch technology". 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 fundamental principle behind the approach is the ability to match individual demand for a commodity with a suitable supply. The suitability of the match depends on the quality required and the quality offered. In the context of utility management, the commodity may be heat, with its quality measured as temperature; or it may be water or hydrogen, the quality of which would be purity or pressure, for example. By maximizing the match between supplies and demands, plants can minimize the import of purchased utilities.



Schematic Process Utility Use

Minimize Utility Use

Figure 5: Schematic Process

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. Pinch analysis provides tools that allow to investigate the energy flows within a process, and to identify the most economical ways of maximizing heat recovery and of minimizing the demand for external utilities (e.g., steam and cooling water).

It also includes opportunities such as reducing operating costs, debottlenecking processes, improving efficiency, reducing and planning capital investment, and reduce waste and emission. Here, the basic problem is to synthesize or retrofit a network of exchangers, heaters, and/or coolers to transfer the excess energy from a set of *hot streams* to a set of *cold streams*, or streams that require heating.

The application of pinch analysis can typically identify:
– Savings in energy consumption: 10% to 35 %;
– Savings in water consumption: 25% to 40 %;
– Savings in hydrogen consumption: up to 20 %.

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 places 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.

The pinch analysis can be applied both for designing of a new enterprise, and at redesigning of an existing unit. But in the latter case, of course, there are features and restrictions concerning energy targeting, disposing of heat exchangers, stream splitting, etc.

Some results of application of the pinch analysis are presented in Tables 1

Table 1: The Analysis of application of the pinch technology in various industries (Smith et al, 2000)

Branch	Saving	Pay-back period
Petrochemistry	40 % of consumed fuel	10 - 24 months
Inorganic chemistry	30 % of total energy	9 - 16 months
Chemistry	30 % of total energy	15 months
Pharmacology	20 - 40 % of total energy	2 - 2,5 years
Polymers	25 % + increase of productivity	Up to 2,5 years
Dyes	15 % of total energy	15 months
Metallurgy	50 % increase of capacity	2 years
Food production	35 % of total energy	1 - 2 years

Pinch technology presents a simple methodology for systematically analyzing 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.

In traditional designing approach, the core of process is designed with fixed flow rates and temperatures so that the heat and mass balance of the process is satisfied. The design of heat recovery systems are provided afterwards and the remaining duties are competed by using the external utilities. In pinch technology approach integration of heat recovery systems is considered together with process designing. A simple map in Fig. 16 shows clearly the differences.

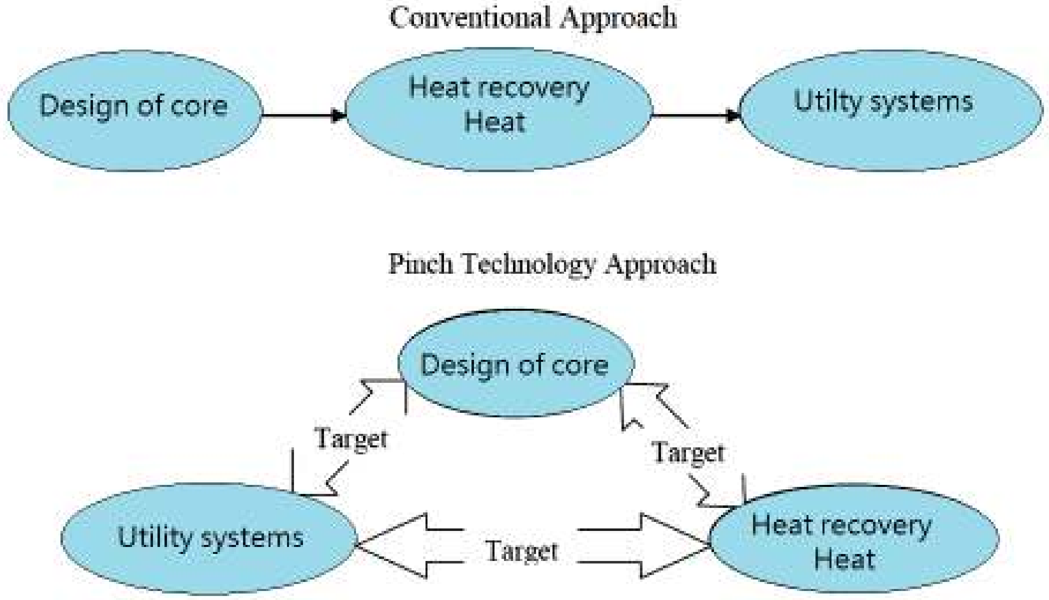


Figure 6: Traditional design approach versus pinch design approach

The ideal time to apply pinch analysis is during the planning of process modifications that will require major investments, and before the finalization of process design. Maximum improvements in energy efficiency, along with reduced investments can be obtained in a new plant design, since many plant-layout and –process constraints can be overcome by redesign

When considering any pinch-type problem, whether it be related to energy, water, or process gas, the same principles apply:

- Processes can be defined in terms of supplies and demands (sources and sinks) of commodities (energy, water, etc.).

- The optimal solution is achieved by appropriately matching suitable sources and sinks.
- The defining parameter in determining the suitability of matches is quality, e.g. temperature or purity.
- Inefficient transfer of resources means that the optimal solution cannot be achieved. In fact, the amount of inefficient transfer is equal to the wasteful use of imported commodities.

A methodology coined

Pinch Analysis was developed in the late 1970s and early 1980s, which resulted in a departure from traditional design practice that had been based on extending and improving process technologies by the use of operating and engineering insight (i.e. following the “learning curve”) and to choose the best design from a set of case studies.

Process integration has already had a profound effect on the chemical process industries, in the form of Pinch Technology and heat-exchanger-network optimization. Pinch Analysis is currently the most widely used. This is due to the simplicity of its underlying concepts and, specially, to the spectacular results it has obtained in numerous projects worldwide.

Pinch technology is a rigorous, structured thermodynamic approach to energy efficiency that can be used to tackle a wide range of process and utility related problems, such as reducing operating costs, debottlenecking processes, improving efficiency and reducing and planning capital investment.

The most important new feature in Pinch Analysis was the ability to establish Performance Targets ahead of design only based on information about the change in thermodynamic state for the process streams, described in table form and hereafter referred to as Stream Data. These targets were first developed for thermal energy (external heating and cooling) and have later been extended to mechanical energy (power or shaft work), number of heat exchangers, and total heat transfer area.

Pinch Technology is a recognized and well proven method in industries such as chemical, petrochemical, oil refining, paper and pulp, food and drinks, steel and metallurgy, etc., leading to an energy saving of 10 to 35%, water saving of the tune of 25 to 40% and hydrogen savings up to 20%. Pinch technology provides a systematic methodology for energy saving in processes and total sites.

A designing procedure which uses the pinch method consists of two stages: determination of targets and design stage. The main advantage of this method consists in interactive character of procedure of designing. The drawbacks of it are the necessity to carry out long-duration manual calculations, and, besides, a possibility of generating of too complicated alternative projects because of the implicit accounting of cost criteria during the calculation.

Heat Integration through Pinch Technology

An important early development of process integration is *pinch technology for heat integration*. The term Heat Integration has two meanings. First, it refers to the physical arrangement of equipment, process sections, production plants, entire sites, and even the surroundings in case of district heating or district cooling. Second, it refers to an area of Process Synthesis, with methods and tools aiming at increased energy efficiency in industrial processes and energy plants.

Such improved energy efficiency can be achieved by combining (i.e. integrating) heating and cooling demands and thereby reducing the need for external heating and cooling utilities. Efficient use of equipment is of course also part of the scope, since energy efficiency only becomes interesting and will be implemented if it is economically feasible.

One of the most practical tools to emerge in the field of process integration in the past 20 years has been Pinch analysis, which may be used to improve the efficient use of energy, hydrogen and water in industrial processes. Pinch analysis is a recognized and well-proven method in each of the following industry sectors:

– Chemicals;
– Petrochemicals;
– Oil refining;
– Pulp & paper;
– Food & drink;
– Steel & metallurgy.

Process integration and pinch technology are used to *analyze* this system to minimize utility consumption and *synthesize* a heat-exchanger network and utility system to achieve this goal. A key breakthrough in the design and retrofit of such networks is the identification of *the pinch-point temperature*. By applying the principles of thermodynamics and energy balances to systematically analyze heat flow across various temperature levels throughout a manufacturing process, we can identify a temperature level, called the pinch point.

Above this point, cooling utilities are unnecessary; below this point, heating utilities are unnecessary. In other words, it is more cost-effective to cool hot process streams above this temperature by using cold process streams than by using cooling utilities. Similarly, it is more cost-effective to heat cold process streams below this point by using hot process streams than by using heating utilities.

Significant developments in pinch technology for heat integration over the past fifteen years have enabled practicing engineers to establish *a prior* a number of attainable targets when designing new heat-exchanger networks, or retrofitting existing networks, including:

- the minimum number of equipment units (i.e., exchangers, heaters and coolers);
- the minimum investment cost of equipment units;
- the minimum operating costs of utilities (i.e., the minimum heating- and cooling utility consumptions).

Pinch technology for heat integration is divided into three tasks:

1. *Analysis*. Identifying, *a priori*, the design targets, such as the minimum consumption of utilities (steam, cooling water and others), the minimum number of heat-exchange units (exchangers, heaters and/or coolers), the minimum surface area of heat-exchange units, etc..
2. *Synthesis*. Designing a heat-exchanger network that achieves the identified design targets.
3. *Retrofit*. Modify an existing process to maximize the use of process-to-process heat exchange and minimize the use of external utilities through effective process changes.

Steps of Pinch Analysis:

1. Identification of 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.

2. Thermal Data Extraction for Process and 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 (T_{supply} ^{o}C) : the temperature at which the stream is available.
   - Target temperature (T_{target} ^{o}C) : the temperature the stream must be taken to.
   - Heat capacity flow rate (MC_P kW/ ^{o}C) : the product of flow rate (m) in kg/sec and specific heat (Cp kJ/kg ^{0}C).

3. Selection of Initial ∆Tmin Value

   The temperature of the hot and cold streams at any point in the exchanger must always have a minimum temperature difference (∆Tmin). This ∆Tmin value represents the bottleneck in the heat recovery.

4. Construction of Composite Curves and Grand Composite Curve

   Temperature - Enthalpy (T - H) plots known as 'Composite curves' is used 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. The grand composite curve (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.

5. 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 QH_{min} and QC_{min} requirements.

6. Estimation of Heat Exchanger Network Capital Cost Targets
7. Estimation of Optimum ΔT_{min} Value
8. Estimation of Practical Targets for HEN Design
9. Design of Heat Exchanger Network (HEN)

The initial data are collected and the table of initial design data is compiled. Then the graph is drawn in coordinates, heat flows of hot and cold streams temperatures. The point of the closest approaching of the curves represents the least temperature difference of the chosen heat exchange circuit, that is the bottleneck of the heat exchange system. It is called "pinch".

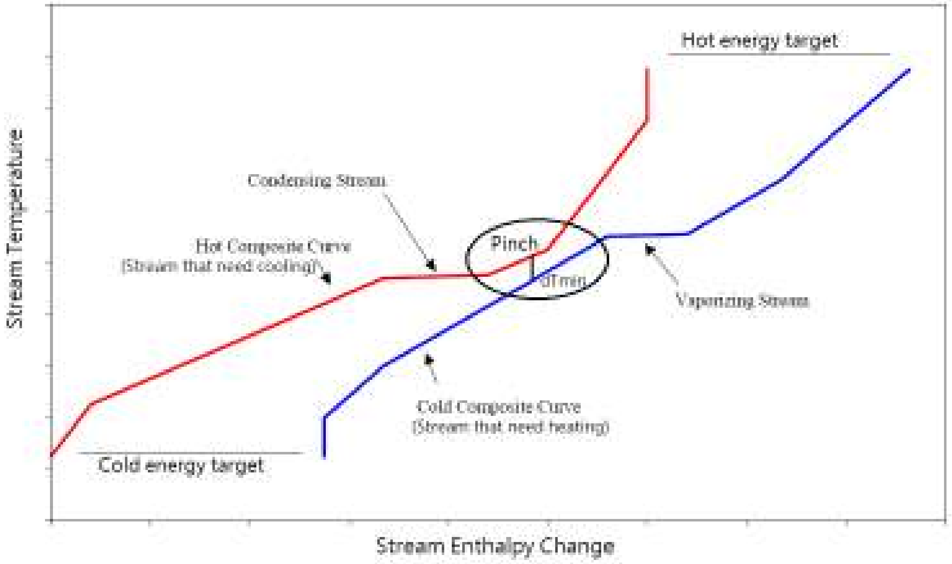


Figure 7: Composite curves determine energy targets before designing

The graphical analysis of these results is performed (Zhulaev, 2012):

- The relation between the hot and cold energy targets (consumption of hot and cold utilities) and the value of the temperature between the hot and cold composite curves in the pinch point is defined

- Designing of the heat exchange network, disposing of the heat exchangers and If necessary, the work of combined heat and power generation systems (steam or gas turbines, heat pumps, refrigeration cycles) can be analyzed.
- Consideration of possibility of changing the process parameters (particularly in reactors, distillation columns, evaporators, dryers, etc.) to increase power saving utilities, simplification of the heat exchange network.

Mass Integration Through Pinch Technology

Mass integration is a systematic methodology that provides a fundamental understanding of the global flow of mass within a manufacturing process and employs this holistic understanding in identifying performance targets and optimizing the generation and routing of species through the process.” In short, a mass exchanger is any direct-contact, countercurrent mass-transfer unit that uses a mass-separating agent (MSA). Mass-exchange operations include absorption, adsorption, ion exchange, leaching, solvent extraction, stripping and similar processes, while mass-separating agents (MSA) include solvents, adsorbents, ion-exchange resins and stripping agents.

Several important questions when retrofitting existing facilities and designing new mass-exchange networks

- What are the maximum amounts of process MSAs that can be employed to remove contaminants from the contaminant-rich process streams with little operating costs?
- What are the minimum flowrates of external MSAs that are required to remove contaminants not extracted by process MSAs and in what order should multiple external MSAs be used?
- How do we design a new mass-exchange network, or retrofit an existing network, to meet these targets?
- How should we modify a manufacturing process to maximize the use of process MSAs and minimize the use of external MSAs?

Pinch technology for mass integration is divided into three tasks:

1. *Analysis*. Identifying, *a priori*, the maximum consumption of process MSAs and the minimum consumption of external MSAs.
2. *Synthesis*. Designing a mass-exchange network that achieves the identified flowrate targets for process and external MSAs.
3. *Retrofit*. Modifying an existing mass-exchange network to maximize the use of process MSAs and minimize the use of external MSAs through effective process changes.

Absorption involves the removal of contaminants from a vapor stream (process stream) with a liquid solvent. contaminants are transferred from the gas phase (entering at the bottom of the unit and exiting from the top) to the liquid solvent (entering at the top of the unit and exiting from the bottom). An industrial example of absorption is flue-gas desulfurization.

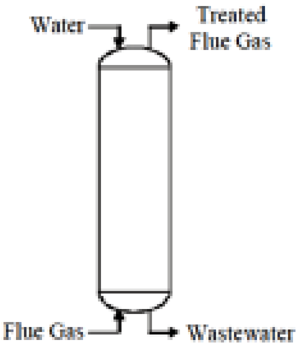


Figure 8: Absorption Unit

Adsorption uses a solid (MSA) to adsorb contaminants from gas and liquid streams (process streams). An example is pressure-swing adsorption as an alternative to cryogenic distillation. Here, nitrogen and other contaminants are selectively adsorbed from air (process stream) on to activated carbon (MSA). The pressure is swung to lower pressures and the contaminants are desorbed or purged to regenerate the bed.

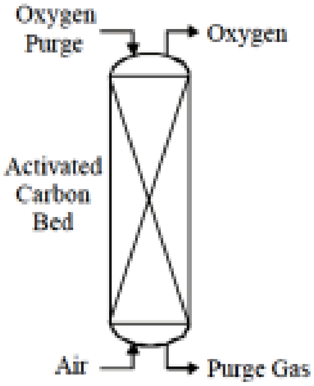


Figure 9: Adsorption Unit

Extraction is the transfer of contaminants from one liquid phase to another in a countercurrent contactor. Industrial operations using extraction are numerous and include mixer-settlers (i.e., a desalter) and packed towers.

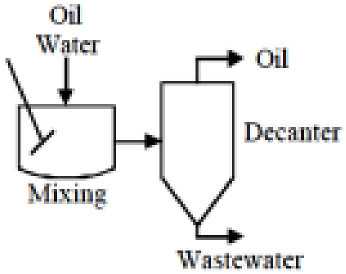


Figure 10: Extraction Unit

Ion exchange employs cation or anion resins (MSA) to replace ionic contaminant species in liquid streams (process stream). A typical ion-exchange bed consisting of a vessel packed with an ion-exchange resin. The resin is regenerated through backwashing as the contaminant level in the product reaches a limiting concentration.

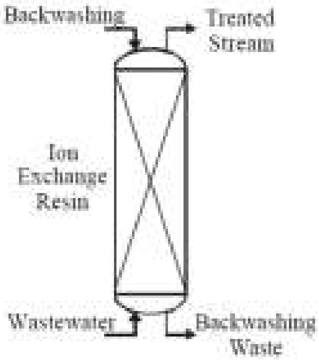


Figure 11: Ion Exchange Unit

Stripping is the transfer of contaminants from a liquid stream (process stream) to a gas Stream, the liquid phase (e.g., a wastewater stream) descending through the column while the gas phase (e.g., air or steam as a MSA) passes countercurrently up the column

Benefits 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. In addition to energy conservation studies, Pinch Technology enables process engineers to achieve the following general process improvements (Cheresource):

1. 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.
2. 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.
3. 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.

4. Comparing practical with theoretical targets quantifies opportunities "lost" by constraints – a vital insight for long-term development.
5. 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.
6. 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.
7. 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.

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 (Cheresource).

1. **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.

2. **Total Site Analysis.** In 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. 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.

3. **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.

4. **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.

5. **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.

6. **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.

7. **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.

DEFINITIONS

Cascade - Set of heat flows through a heat recovery problem, in strict descending temperature order

Cascade analysis - The method of batch process analysis based on breaking the process into time intervals and developing time-dependent heat cascades.

Cold stream - Process stream requiring heating.

Composite curve - Combined temperature-enthalpy plot of all hot or cold streams in a problem.

Data extraction - Definition of data for energy integration studies, from a given flowsheet.

Debottlenecking - Increasing the production capacity of a plant by identifying and removing rate-limiting steps, such as slow processing stages or heavily occupied equipment items.

Extracted streams or **extracted process -** A set of streams removed from the process stream data to test them for appropriate placement.

Feasible cascade - Heat cascade in which net heat flow never becomes negative and is zero at the pinch.

Flowing stream - A stream which receives or releases heat as it flows through a heat exchanger

Grand composite curve (GCC) - Plot of heat flow vs. temperature from a heat cascade

Grid - System of horizontal and vertical lines with nodes, for representing heat exchanger networks.

Heat cascade - A table of the net heat flow from high to low temperatures divided up into temperature intervals

Heat exchanger network (HEN) - System of utility heaters and coolers and process interchangers

Hot stream - Process stream requiring cooling.

Infeasible cascade - Heat cascade with zero hot utility and some negative values of net heat flow

Maximum energy recovery (MER) - Best possible energy recovery in a heat exchanger network for a given value of Δ*T*min; also known as minimum energy requirement

Pinch - Point of zero heat flow in a cascade (alternatively, point of closest approach of composite curves in a “heating and cooling” problem).

Pinch design method - Method of heat exchanger network design which exploits the constraints inherent at the pinch.

Pinch match - Process interchanger which brings a stream to its pinch temperature (i.e. hot streams above the pinch, cold streams below).

Pocket - Region in the grand composite curve where neither external heating nor cooling is required.

Shifted composite curves - Plots of combined enthalpy of all hot and all cold streams against shifted temperature, touching at the pinch.

Shifted temperature - Stream temperatures altered to include the effect of the required Δ*T*min, usually by reducing hot stream temperatures by Δ*T*min/2 and increasing cold stream temperatures by Δ*T*min/2.

Split grand composite curve - Plot of the grand composite curve for the background process and the extracted streams on the same graph.

Supply temperature - Temperature at which a process stream enters a heat recovery problem.

Target - A design performance limit, determined prior to design.

Target temperature - Temperature at which a process stream leaves a heat recovery problem.

Temperature interval Section of a heat recovery problem between two temperatures which contains a fixed stream population

Utility System of process heating or process cooling.

Unit Process interchanger, heater or cooler.

Δ*T*min Minimum temperature difference allowed in the process between hot and cold streams.

Δ*T*min contribution (Δ*T*cont) Temperature difference value assigned to individual process streams. Match-dependent Δ*T*min values are given by the sum of the contributions in a match.

NOMENCLATURE

A	Heat transfer area (m2)
C_P	Specific heat capacity (kJ/kg K)
H	Flow enthalpy (kW)
ΔH	Change in flow enthalpy (kW)
Q	Heat flow (kW)
QH_{min}	Minimum feasible hot utility (kW)
QC_{min}	Minimum feasible cold utility (kW)
S	Shifted temperature (°C or K)
S_S	Shifted supply temperature of process stream (°C or K)
S_T	Shifted target temperature of process stream (°C or K)
T_{Supply}	Supply temperature of process stream (°C or K)
T_{Target}	Target temperature of process stream (°C or K)
ΔT	Temperature difference (K)
ΔT_{cont}	ΔT_{min} contribution of an individual stream (K)
ΔT_{min}	Minimum allowed temperature difference (K)