Holistic Approach for Resource Conservation

Concerns about environmental sustainability, rising costs of raw materials and waste treatment are amongst the factors that accelerate the chemical process industries to opt for more sustainable resource conservation practices. Through this article we present an in-depth study on Pinch Analysis, a holistic approach to conserve various resources in chemical process plants.

Chemical process industries require significant amount of different natural resources such as energy, freshwater, cooling water, hydrogen, raw materials, etc. Efficient utilisation of these resources is of utmost importance for market competitiveness. Pinch Analysis comprises of a set of systematic and algebraic methods for designing (both grassroots as well as retrofits) integrated production systems with a special emphasis on improving efficient utilisation of various resources.

Almost four decades ago, Pinch Analysis began as a thermodynamic-based approach to energy conservation in chemical process industries. Over the years, it has evolved to become a powerful tool for resource conservation. Pinch Analysis has been successfully utilised in analysing heat exchanger networks to conserve thermal energy, multiple utility systems to conserve fuel, mass exchanger networks to conserve mass separating agents, water allocation networks to reduce freshwater requirement, treatment unit networks to reduce operating and capital costs, distillation column optimisation to reduce energy requirement, appropriate production planning strategies, etc. Methodologies of Pinch Analysis help in providing physical insight of the resource conservation issues through graphical representations and simplified tableau-based calculation procedures. Pinch Analysis, a conceptual approach based process integration technique, recognises the importance of setting targets prior to the detailed design of the process. This helps in screening different process design alternatives and identifying directions for significant improvements, especially in conserving various resources.

Three major features of Pinch Analysis methodologies

1. Development of physical insight about process design while conserving various resources
2. Use of thermodynamic principles
3. Applications of optimisation techniques

The ability to set targets prior to the detailed design has been a key element in the success of Pinch Analysis. Graphical representations of Pinch Analysis assist the process designer to take the right direction in making appropriate decisions.

The Pinch Concept

Origin of Pinch Analysis lies with the concept of heat recovery pinch point in conserving thermal energy in heat exchanger networks. Heat Exchanger Network Synthesis (HENS) is an important field in process engineering. In a process plant, process streams to be cooled and/or heated from some specified supply temperatures to another specified the final temperatures. For all these streams, heat capacities and flow rates are given. Primary objective is to develop a Heat Exchanger Network (HEN) with minimum annualised investment and operating costs.

In 1944, Ten Broeck published the first HEN related paper. However, a systematic procedure, based on the conceptual and thermodynamic understanding, to solve this problem was developed by Hohmann, as a PhD thesis to the University of Southern California in 1971[1]. As the work was little ahead of time (first oil shock came in 1973), attempts to publish this work in academic journals were turned down repeatedly. The pioneering work of Umeda and his coworkers at Chiyoda[2] and independently, the work of Linnhoff and Flower[3] laid the foundations of modern Pinch Analysis with the identification of heat recovery pinch point. Professor Linnhoff's group at Manchester, UK developed this concept into an industrial technology.

Subsequently, many mathematical optimisation based methodologies have been proposed. In 2001, it has been mathematically proved that such a problem is NP-hard[4] and thereby refutes the possibility for existence of polynomial time optimisation algorithms. This emphasises the importance of the sequential optimisation techniques, employed by Pinch Analysis methods, to address large dimensional industrial problems. The contributions of Pinch Analysis are to target the minimum utility requirement before design of HEN and also to provide the physical insight to match the streams for placing heat exchanger in the network to achieve targeted minimum utility requirement. The energy targets can be obtained using one of the Pinch Analysis tool called as 'Composite Curves'.

Composite Curves and Energy Targets

Composite curves consist of Temperature-Enthalpy (T-H) profiles of heat availability and heat demands in the process. The heat availability profile as a function of temperature is called Hot Composite Curve (HCC) and heat requirement profiles as a function of temperature is called the Cold Composite Curve (CCC). Typical composites curves are shown in Figure 1 (on next page). The benefit of this method is that multiple hot and cold streams can be represented as a single pseudo-hot stream and a single pseudo-cold stream.

Composite curves indicate the minimum energy target for a process, which is achieved by overlapping the hot and cold composite curves, as shown in Figure 1, separating them by the minimum temperature difference ΔT_{min} to satisfy the second law of thermodynamics. This overlap shows the maximum process heat recovery possible, indicating that the remaining heating and cooling needs are the minimum hot utility requirement (Q_{hu}) and the minimum cold utility requirement (Q_{hu}) of the process for the chosen ΔT_{min}.

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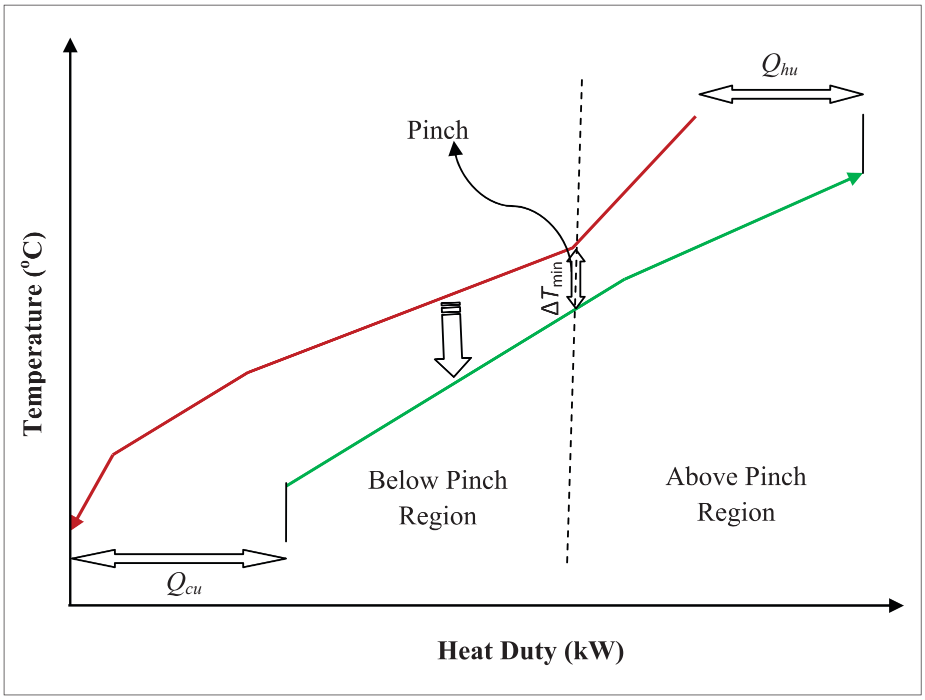

Figure 1: Energy Targeting through Composite Curves

The Pinch Principle

The point where ΔT_{min} is observed is known as the 'Pinch' (see Figure 1). Once the pinch point has been identified, it is possible to consider the process as two separate systems: one above and one below the pinch, as shown in Figure 1. The system requires heat above the pinch point (a high temperature heat deficit zone) and rejects heat below the pinch point (a low temperature heat surplus zone). These two zones are thermally independent. Transfer of heat from the 'high temperature heat deficit zone' to 'low temperature heat surplus zone' is thermodynamically possible. However, this leads to increased utility requirements. Based on these observations, three golden rules of thermal Pinch Analysis are developed. These rules must be obeyed in order to achieve the minimum energy targets for a process; otherwise, there will be a double energy penalty for the system.

Three golden rules of Pinch Analysis

1. No heat transfer across the pinch
2. No cold utility above the pinch
3. No hot utility below the pinch

Pinch Analysis has been applied to many industries. Typical savings identified through the application of heat pinch are reported in literature[5] as follows:

Typical savings identified through application of heat pinch	
Industries	**Percentage**
Oil refining	10 – 25
Petrochemicals	15 – 25
Iron and steel	10 – 30
Chemicals	15 – 35
Food and drink	20 – 35
Pulp and paper	15 – 30

Recent Developments in Pinch Analysis

Recently, tools of Pinch Analysis have been developed to conserve various other resources. One of the prominent directions of the evolution and development of Pinch Analysis is to extend the applicability of Pinch Analysis towards new areas by applying various analogies. The most obvious analogy is between heat transfer and mass transfer. In heat transfer, heat is transferred with temperature difference as the driving force. Similarly, in mass transfer, mass (or certain components) is transferred with concentration difference as the driving force. The corresponding Mass-Pinch, developed by El-Halwagi and Manousiouthakis[6], has a number of industrial applications whenever process streams are exchanging mass in a number of mass transfer units, such as absorbers, extractors, etc.

One specific application of the Mass-Pinch is in the area of Water-Pinch, related to water management in process industries, where optimal use of water and wastewater is achieved through reuse, regeneration and recycling[7]. The corresponding Water-Pinch can also be applied for design of Treatment-Pinch of distributed effluent treatment processes[8]. The most recent extensions are the Hydrogen-Pinch technology for hydrogen management in refineries[9] and Material-Pinch for material reuse networks[9]. These days oil refineries experience an increasing need for hydrogen to meet new product specifications (for example on diesel and gasoline). The Hydrogen-Pinch method is a tool to optimize the hydrogen distribution system and to evaluate the scope for introducing purification units (such as PSA, membranes and cryogenic units). Pinch Analysis based methodologies have also been extended to processes and utility systems, from scheduling to strategic planning, continuous to batch processes, reactors, separators, integration between processes, emissions reduction to pollution prevention, aggregate production planning, sizing renewable energy systems, etc.

Conclusion

The major contribution of Pinch Analysis is based on the generalised problem definition and solution methodologies. A generalised problem definition can be obtained through

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Flows	Qualities	Examples/Problems
Heat	Temperature	• Heat integration (1971, 1979) • Total site integration (1984) • Integration of thermal equipments (1982)
Mass	Concentration	• Mass integration (1989) • Water/Hydrogen management (1994,1996) • Pollution prevention/Treatment networks
Mass	Properties	• Recycle/Reuse networks (2004)
Steam	Pressure	• Cogeneration (1993, 2008)
Energy	CO_2	• Carbon-constraint energy planning (2007)
Mass	Time	• Supply chain management (2002)
Energy	Time	• Standalone energy system (2007) • Isolated power system (2007)

Table 1: Generalised Flows and Qualities in Pinch Analysis.

the concept of flows and associated qualities. Flows are usually represented by non-negative real numbers whereas qualities are represented with real numbers. Table 1 shows the examples of different flows and qualities along with examples.

Another important contribution of Pinch Analysis is to set targets prior to the detailed design activities. Targeting may be defined as prediction of the optimum performance of a system prior to any synthesis/detailed design. Targeting provides physical insights to the designer. It also serves a tool for preliminary analysis and screening of numerous design alternatives. In summary, the pinch concept is a systems tool since it provides critical information on a total plant or even site level. ■

References

- *Hohmann, 1971. Optimum Networks for Heat Exchange. Ph.D. Thesis. University of Southern California.*
- *Umeda, T.; Itoh, J.; Shiroko, K. Heat Exchange System Synthesis. Chem. Eng. Prog. 1978, 74 (7), 70–76.*
- *Linnhoff, B.; Flower, J. R. Synthesis of Heat Exchanger Networks I. Systematic Generation of Energy Optimal Networks. AIChE J. 1978, 24 (4), 633–642.*
- *Furman, K. C.; Sahinidis, N. V. Computational Complexity of Heat Exchanger Network Synthesis. Comput. Chem. Eng. 2001, 25 (9–10), 1371–1390.*
- *http://cetc-varennes.nrcan.gc.ca, Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen.*
- *El-Halwagi, M.M., Manousiouthakis, V., 1989. Synthesis of Mass Exchange Networks. AIChE J 1233-1244.*
- *Bandyopadhyay, S., Ghanekar, M.D., Pillai, H.K., 2006. Process Water Management. Ind. Eng. Chem. Res. 45, 5287–5297.*
- *Bandyopadhyay, S., 2009. Targeting Minimum Waste Treatment Flowrate. Chemical Engineering Journal. 152, 367–375.*
- *Bandyopadhyay, S., 2006. Source Composite Curve for Waste Reduction. Chemical Engineering Journal 125, 99–110.*

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Chevron Phillips to Build Ethylene Facility in Texas

Texas, USA: Chevron Phillips Chemical Company, a joint venture equally owned by Chevron Corporation and ConocoPhillips plans to build one of the first new ethylene production facility in Baytown, Texas with an investment of USD 5 billion. The company chose its Baytown, Texas facility to convert ethane into ethylene. The investment includes an ethylene plant, known as a cracker, capable of producing 1.5 million metric tons of the gaseous chemicals annually, and two plants for making polyethylene plastic. Ethane is derived from gas, which has dropped in price as new technologies have boosted production from shale formations. The US has a cost advantage relative to producers in Asia and Europe where ethylene is made from oil-derived naphtha.

"We are pleased that the development of shale-gas resources in the United States has set the stage for major petrochemical investment and job creation in our backyard," Peter L Cella, Chief Executive Officer of Chevron Phillips, said in the statement. The company plans to convert ethylene from its new cracker into 1 billion metric tons a year of polyethylene at plants to be built at either the company's Cedar Bayou site in Baytown or at the nearby Sweeny site in Old Ocean. A final selection will be made by March, the company said. Polyethylene is a plastic used in grocery bags and food packaging.The company chose to build a site adjacent to an existing cracker in Baytown because of its proximity to ethane, ethylene pipelines and storage caverns. The plants will employ 400 people and the construction project will create 10,000 jobs. Dow Chemical Co., the world's largest ethylene producer, plans to spend USD 4 billion in the US to build a Gulf Coast cracker by 2017, two propylene plants and to reopen an idled Louisiana cracker. Sasol Ltd. may spend as much as USD 4.5 billion to build a cracker and related plants in Louisiana.