Systematic Design and Synthesis Of Heat, Mass and Water Recovery Networks Using Pinch Analysis

Zainuddin Abdul Manan

Process Systems Engineering Group, Department of Chemical Engineering, Faculty of Chemical & Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA.
Tel: +607-5535512, Fax: +607-5581463, E-mail: zain@fkkksa.utm.my

Abstract

This paper highlights some of the key recent advances in research related to Pinch Analysis, particularly those developed in the Department of Chemical Engineering, Universiti Teknologi Malaysia. The focus is on the development of systematic conceptual and heuristic design and retrofit techniques for efficient heat, mass and water recovery even though many recent work in the area has also concentrated on the use of mathematical programming.

Keywords:

Pinch Analysis, Mass Exchange Network, Water Pinch, Simultaneous Energy and Water, MATRIX, Heat-MATRIX.

Introduction

The current drive towards environmental sustainability and the rising costs of fuel and water have encouraged the process industry to find new ways to reduce energy and water consumption. Maximising energy and water recovery and reuse can minimise consumption and reduce environmental emissions. Concurrently, the development of systematic techniques for energy and water reduction within a process plant has seen extensive progress. The advent of Pinch Analysis as a tool for the design of optimal heat, mass and water recovery network has been one of the most significant advances in the area of process synthesis over the last ten years [1].

In the area of heat recovery, a technique named MATRIX that is capable of considering a wide range of existing design constraints has been introduced for the retrofit of heat recovery network. Work is underway to develop new visualization tools to assist the simultaneous reduction of energy and water in process plants. In this work, a local paper mill has been used as a case study. The development of systematic methods for the synthesis of batch mass exchange network systems has also been one our recent main focus areas. Finally, a new numerical technique for establishing the minimum water and wastewater targets is the most recent technique we have introduced in Pinch Analysis. Most of these recent developments have been successfully incorporated in Heat-MATRIX, the Pinch Analysis software developed by the Process Systems Engineering Group, Department of Chemical Engineering, Universiti Teknologi Malaysia.

The New MATRIX Technique [2]

A new systematic technique aimed at reducing the hot and cold utility consumption through the revamp of existing heat exchanger network in a chemical process has been successfully developed. The technique has been utilized for the retrofit of a palm oil refinery with dramatic results. This new technique, which is called MATRIX (**MA**ximising the **T**otal area **R**euse **I**n an e**X**isting network) is focused, and requires much less diagnosis effort. MATRIX combines thermodynamic insights and graphical approach to systematically guide users to explore all possible heat exchange match options and screen the most promising one. This technique consists of three-stages: *Match Identification*, *Match Screening* and *Network Evolution*. In the Match Identification stage, a new graphical visualisation tool called the Exergy Block Diagram (EBD) is proposed to identify all possible heat exchanger. Next, a systematic screening technique called the *Match Matrix* (M-Matrix) is proposed to sort and filter out the undesirable match options identified from the EBD. The final stage of retrofit is network evolution that involves a systematic loop and path optimisation technique to generate the final retrofit scheme. A case study on a local palm oil refinery was used to demonstrate the advantage of this approach for the retrofit of existing heat exchanger network. Economic analysis conducted showed projected utility savings of more than RM 80,000 (65 %) in hot utility and RM 25,000 (48%) in cold utility. An investment of RM 44,000 in heat transfer area was required to realise these savings. The minimal structural modifications lead to the small capital investment and hence, a very attractive pay back period of about 5 months.

Mass Exchange Network [3]

Synthesis of optimal MEN for continuous processes based on Pinch Analysis has been rather well established. In contrast, very little work has been done on mass exchange network synthesis (MENS) for batch process systems. Techniques developed for the MENS for batch systems

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involved the following two key steps: 1. Setting MEN design targets ahead of design that include the utility and the number of units targets; 2. MEN design to achieve the design targets. Utility targeting employs the vertical and horizontal cascading approaches that have been adapted from heat exchange network synthesis (HENS) for batch processes. Prior to MEN design, the targeting procedure establishes the minimum utility (solvent) requirement for maximum mass recovery (MMR), maximum mass exchange (MMX) and maximum mass storage (MMS). These targets are essential for network design and batch process rescheduling. A systematic procedure for MEN design for batch processes, which include the new graphical tools called the time-grid diagram (TGD) and overall time-grid diagram (OTGD) have been introduced to allow designers to achieve the utility targets established for the MEN. The minimum number of mass exchange units target has also been developed to provide a lower bound for the number of units for a preliminary batch MEN. Finally a technique to evolve the batch MEN has been developed based on the conventional approach from the continuous MEN design.

Water Minimisation

The development of systematic techniques for water reduction, reuse and recycling within a process plant has seen extensive progress. The advent of Water Pinch Analysis (WPA) as a tool for the design of optimal water recovery network has been one of the most significant advances in the area of water minimization over the last ten years [4]. A numerical method to establish the minimum water target for applications beyond mass transfer-based water-using processes is however unavailable. The Water Cascade Analysis (WCA) described in the following section has been very have recently developed by our group to fill in this research gap.

The Water Cascade Analysis (WCA) Technique [5]

A new method to establish the minimum water and wastewater targets for continuous water-using processes, known as the Water Cascade Analysis (WCA), is one of the latest techniques for water targeting developed by our group. WCA is a numerical technique that can quickly yield accurate water targets and pinch point locations for a water network. By eliminating the tedious iterative steps of the water surplus diagram, WCA offers a key complimentary role to the water surplus diagram in the design and retrofit of water recovery network. Various options involving process changes, including water regeneration and equipment modifications can be systematically assessed using the WCA. Problems involving multiple pinches can now be handled more efficiently, accurately and with much less effort. All the key features and the systematic nature of the WCA make it easy for the technique to be automated and translated into any computer language for software development. As our experience has shown, the WCA has simplified the task of incorporating the water surplus diagram in a computer software by eliminating the tedious iterative steps involved during the construction of water surplus diagram. The WCA feature has been incorporated in *Heat-MATRIX*, a new software for energy and water reduction developed by the Process Systems Engineering Group, Department of Chemical Engineering, Universiti Teknologi Malaysia [5].

Water Minimisation on a Local Paper Mill Plant [6]

The manufacture of pulp and paper is a water intensive industry. Due to the increase in the price of process water, the industry is under regulatory pressure to reduce the fresh water usage. In view of this problem, a research to minimise the water consumption on an existing paper mill was carried out. Process integration methodology such as Water Pinch Technology was applied to scrutinise the effectiveness of the existing water network and identify the opportunities for fresh water reduction. The Malaysian Newsprint Industries paper mill plant was selected as the case study for the research. The study involves two main scopes, i.e. fresh water targeting and water network design. To establish the minimum water targets, the Heat MATRIX software which implements the new water cascade analysis technique developed by the PSE group in UTM was used in conjunction with the graphical techniques of composite curves and water surplus diagram. Targeting was followed by the design of a water distribution network to achieve the minimum water targets. The design technique based on water source and water demand approach was implemented. From the research conducted, a total reduction of 19.63% of fresh water consumption for the mill was identified and some minor modifications on the water network configuration for the paper mill were proposed. With the implementation of this water network, the paper mill can potentially achieve an annual fresh water cost savings of RM 118400 which include the pumping costs, the chemical costs and other raw water treatment costs [6].

Simultaneous Energy and Water Reductions [7]

Water and energy are both used in significant quantities in process industries. Even though the procedure for the optimal design of a water minimisation network and that of energy recovery network have been very well established, the available techniques to optimize the network of heat and water systems mentioned above are still largely independent and significantly lacking in terms of their ability to capitalize on the synergy between one another. Based on these independent techniques, reduction of energy does not guarantee the minimum of water usage in process industries and vice versa.

A new systematic technique that minimizes water and energy consumption of a water-using network simultaneously is undergoing development in UTM. Thermodynamic insights and graphical approach were used to assist designers in designing a new water-using network in order to get minimum utility consumptions under optimum

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operating conditions. Among the features, a plot of temperature versus streams flowrate, termed as 'W & E Composite Curves', was a novel graphical tool developed in this research to guide water and energy minimisation simultaneously. The 'W&E Composite Curves' provided key information on the state of a water-using network and allowed water-using network design to be carried out graphically and hence effectively.

Heat-MATRIX [8]

To facilitate the design and improvement of new as well as existing plants, we have integrated and incorporated the traditional Pinch Analysis techniques and the latest developments in the area of heat, mass and water recovery into *Heat-MATRIX*, a computer software developed in UTM. *Heat-MATRIX* has been tailored for the retrofit (improvement) of heat and water recovery network to reduce energy and water in chemical process plants. The software was developed based on the synergistic combination of three key techniques to reduce the hot and cold utility consumption. The software implements the established principles of Pinch Analysis for a new plant, and the new *MATRIX* technique for the retrofit (improvement) of existing processes to reduce the hot and cold utility usage. The *MATRIX* technique is a new methodology that is aimed at improving heat recovery by *MA*ximising the *T*otal *R*euse of the e*X*isting heat recovery network area *(MATRIX)*. The third technique being implemented is the WCA technique described earlier.

Heat-MATRIX is the first computer software for heat and water networks design that implements the *MATRIX* and WCA techniques. It is a Microsoft Windows-based programme that was developed to automate, and rapidly as well as efficiently assist the design and retrofit of a heat recovery network. It also enables the rapid determination of the minimum energy and water requirements for a process, and the improvement of heat recovery network structure for a process plant to achieve the minimum hot and cold utility consumption. In addition, *Heat-MATRIX* can also automatically generate the optimal utility combination for a given process and allow the automatic and semi-automatic design of heat exchanger network to achieve the energy targets. Due to its capability to examine a wide variety of heat exchanger match possibilities, and the inclusion of the capital and operating costs during network evolution, the software offers an attractive, practical and cost-effective alternative solution for heat recovery network retrofit.

Conclusion

Water and energy are the two most common utilities and the main operating costs in a chemical process plant. Steam, which is used for utility heating is the most common form of energy supply in a process that is produced by burning fuel. With the increase in water and fuel prices, chemical process plants are under pressure to improve their profit margin or face possible closure of plants.

Some the key recent advances in research related to Pinch Analysis has been highlighted. The focus is on the development of systematic conceptual and heuristic design and retrofit techniques for efficient heat, mass and water recovery. In the area of heat recovery, a technique named MATRIX that is capable of considering a wide range of existing design constraints has been introduced for the retrofit of heat recovery network. Work is underway to develop new visualization tools to assist the simultaneous reduction of energy and water in process plants. In this work, a local paper mill has been used as a case study. The development of systematic methods for the synthesis of batch mass exchange network systems has also been one our recent main focus areas. Finally, a new numerical technique for establishing the minimum water and wastewater targets is the most recent technique we have introduced in Pinch Analysis. Most of these recent developments have been successfully incorporated in *Heat-MATRIX*, the Pinch Analysis software developed by the Process Systems Engineering Group, Department of Chemical Engineering, Universiti Teknologi Malaysia.

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