TOWARDS SUSTAINABLE DEVELOPMENT USING PINCH ANALYSIS

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ABSTRACT

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. This paper presents the key innovations in process integration for conservation of resources and utilities such as heat, water, power, solvent and gas that have been exclusively developed by Process Systems Engineering group, Department of Chemical Engineering, UTM. The ultimate goal of the innovations is to significantly contribute towards sustainability through the development of tools that enables the conservation of such valuable resources to mankind. The tools and techniques developed include the new MATRIX technique for heat recovery network retrofit, cascade analysis technique for setting the minimum resource conservation targets, new graphical techniques for setting water and energy targets, batch water targeting and network design, retrofit network design, retrofit and optimization of new and existing regeneration units, and new holistic framework for minimum water network and a systematic method for economical water design system. Significant inroads have also been in shifting the pinch analysis paradigm from the traditional focus on water minimization for process industry into the domain of urban water systems. These tools have been incorporated in MATRIX, a software for resource conservation developed in UTM. In view of the latest development in pinch analysis for resource conservation, it is envisioned that the tool can yield significant benefits to mankind and bring us a step closer towards achieving our ultimate goal of sustainable development.

Keywords: Pinch Analysis, minimum water network, holistic framework, MATRIX, resource conservation, sustainability.

1 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 (Manan, 2003).

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. A technique to target power reduction consumed by pumps and turbines has also been introduced. In the area of MEN, a method to target batch retrofit network has been developed. Far and foremost, in the area of water recovery, a new technique named Cost Effective Minimum Water Network (CEMWN) that considered holistically all water conservation approach including elimination, reduction, reuse/recycling, outsourcing and regeneration applicable for industry and urban sector has

been introduced for the first time which contributes to the actual minimum water network. Aside from that, a numerical method called the water cascade analysis (WCA) has also been developed as well as work on maximum water recovery retrofit network design and regeneration optimization. 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. Most of these recent developments have been successfully incorporated in Heat-MATRIX and Water-MATRIX, the Pinch Analysis software developed by the Process Systems Engineering Group, Department of Chemical Engineering, Universiti Teknologi Malaysia.

2 ENERGY CONSERVATION (HEAT AND POWER MINIMISATION)

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. A new look in power savings using power pinch technique has also been explored.

2.1 MATRIX TECHNIQUE AND POWER PINCH (YEE AND MANAN, 2001; MAT NAWI AND MANAN, 2004)

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.

In targeting the minimum power requirements for a large scale process plant, a new graphical visualisation technique called power composite curves for targeting the minimum power requirement in a chemical site (Mat Nawi and Manan, 2004). An ethylene complex is used as a case study to illustrate the impact of the technique. Use of the power composite curves allow an engineer to visualise the overall potential for power generation from a series of turbines and power consumption and make decision on the maximum power recovery and minimum power input from the national grid.

3 MASS EXCHANGE NETWORK BATCH TARGETING AND NETWORK DESIGN (FOO *ET AL.*, 2004 AND 2005)

Synthesis of optimal MEN for continuous processes based on Pinch Analysis has been rather well established as compared to work on mass exchange network synthesis (MENS) for batch process systems. Techniques developed for the MENS for batch systems 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.

4 WATER CONSERVATION

Six new developments in water minimization research have been addressed as described next.

4.1 WATER CASCADE ANALYSIS (MANAN *ET AL.*, 2004)

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.

4.2 MAXIMUM WATER RECOVERY FOR URBAN SECTOR (MANAN *ET AL.*, 2006a)

Pinch Analysis has been an established technique for the design and retrofit of heat, mass and water recovery networks in industry to achieve maximum energy and mass efficiency. Until today, *Pinch Analysis* application is perceived to belong exclusively to the process engineering domain. Water cascade technique based on *Pinch Analysis* was adapted to establish the minimum water and wastewater targets for a mosque in an urban area prior to the design of a water recovery network. The results of our research show a maximum potential reduction of 85.5% fresh water and 67.7% wastewater for the mosque after considering water recovery and regeneration. This work represents a shift in the traditional process engineering paradigm to allow *Pinch Analysis* application to be extended beyond the frontiers of process industry.

4.3 RETROFIT NETWORK DESIGN (TAN AND MANAN, 2004)

Concentration block diagram (CBD) by Tan and Manan (2004) presents a new systematic technique for the retrofit of existing water network based on pinch analysis for non-mass transfer-based processes. CBD enables the existing water network to be viewed in the context of the water flowrate as well as contaminant concentration. This technique, which was applied on a paper mill consists of three main steps: Network Diagnosis, Network Retrofit and Network Evolution. Network diagnosis step provides a good understanding of the existing water network through the use of a new tool called the Concentration Block Diagram (CBD). Next, modifications based on a set of pinch rules were performed on the existing water network to achieve the preliminary retrofit design. Finally, the preliminary retrofit design will go through an evolution to generate the final retrofit scheme.

4.4 RETROFIT AND OPTIMIZATION OF NEW AND EXISTING REGENERATION UNITS (FOO *ET AL.*, 2006)

Optimisation of existing water regeneration units has so far been largely overlooked. As a result, many existing regeneration units tend to operate at efficiencies lower than those

achievable in practice. The new technique proposes that any revamp of a water network should consider process changes as well as optimisation of existing water regeneration units. It demonstrates some new systematic retrofit techniques to employ process changes and to optimise existing regeneration units to reduce utility consumption. Optimisation of existing regeneration units provide opportunity to further reduce utility savings before the installation of new regeneration units. Hence, this retrofit option possesses the advantage of low capital investment and minor process changes over other retrofit approaches. The new methodology for water network retrofit is based on water pinch analysis technique approach via a two-stage systematic procedure. In the first stage, retrofit targets (utility savings and capital investment) were determined for a range of total flowrate and/or outlet concentration of the regeneration unit to obtain a savings versus investment curve. Once the retrofit targets were identified, the existing water network was re-designed to meet the established targets.

4.5 NEW HOLISTIC FRAMEWORK FOR MINIMUM WATER NETWORK (MANAN *ET AL.*, 2006b)

Manan *et al.* (2006b) has suggested the use of water management hierarchy (WMH) (Manan and Wan Alwi, 2006) in conjunction with pinch analysis in order to achieve the minimum water design for the application in both the industrial and urban sector. Minimum water design can be defined as the optimum network design that achieves the maximum water reduction, and hence, maximum savings after considering not only reuse and recycling, but all conceivable methods to holistically reduced water usage through elimination, reduction, reuse/outsourcing and regeneration. The original pinch analysis method only focussed on maximum water recovery i.e. the maximum amount of water recoverable via water reuse and recycling. The method comprises of three main key steps that is (1) Specify the limiting water data, (2) Determine MWR targets, and (3) Screen process changes using water management hierarchy (WMH). Application of MWN technique on a semiconductor plant showed that savings of up to 85.5 % fresh water and 97.8% industrial waste water were achievable with an estimated payback period of 4.6 month.

4.6 A SYSTEMATIC METHOD FOR ECONOMICAL WATER DESIGN SYSTEM (WAN ALWI AND MANAN., 2006)

A cost-effective minimum water design for industrial and urban sector can be achieved by using a new powerful technique termed as *Systematic Hierarchical Approach for Resilient Process Screening* (SHARPS). *SHARPS* can provide a quick and efficient means to guide and screen inferior process changes and predicts the potential maximum fresh water savings and the desirable investment limits during the early design stage. *SHARPS* uses two simple strategies that states the most non-cost-effective process change cost can be reduced either by changing the process change equipment type or by reducing the amount of process changes. SHARPS helps a designer to make quick and fast decision in employing the most cost efficient water conservation solutions that meet their payback period criterion. Application of CEMWN technique on a semiconductor plant showed that savings of up to 85.1 % fresh water and 97.7% industrial waste water were achievable with an estimated payback period of 4 month. Application of the same method on a mosque building gives a savings of up to 90.5% freshwater and 59.3% wastewater achievable within a payback period of 3 years for grassroots case and 97.5% freshwater and 67.2% wastewater achievable within a payback period of 5 years for retrofit case.

5 SIMULTANEOUS ENERGY AND WATER REDUCTIONS (TEA AND MANAN, 2002)

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 has been developed by our research group 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 operating conditions.

The latest new feature developed recently by our group is a plot of temperature versus streams flowrate, termed as 'W & E Composite Curves' (water and energy composite curves). This is 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.

6 MATRIX SOFTWARE (Heat-MATRIX© 2006 and Water-MATRIX© 2006)

Heat-MATRIX Water-MATRIX are software modules for water and energy conservation that is founded on the technique and principles of *Pinch Analysis*, which is an established tool for the design and retrofit (improvement) of optimal heat, mass and water recovery networks in industry to achieve maximum energy as well as mass efficiency.

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* and Water-MATRIX have been tailored for the retrofit (improvement) of heat and water recovery network to reduce energy and water in chemical process plants. The software implements the established principles of Heat and Water 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 WCA feature has been incorporated in Water-MATRIX,

7 CONCLUSION

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. A technique to target power reduction consumed by pumps and turbines has also been introduced. In the area of MEN, a method to target batch retrofit network has been developed. Far and foremost, in the area of water recovery, a new technique named Cost Effective Minimum Water Network (CEMWN) that considered holistically all water conservation approach including elimination, reduction, reuse/recycling, outsourcing and regeneration applicable for industry and urban sector has been introduced for the first time which contributes to the actual minimum water network. Aside from that, a numerical method called the water cascade analysis (WCA) has also been developed as well as work on maximum water recovery retrofit network design and regeneration optimization. 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. Most of these recent developments have been successfully incorporated in Heat-MATRIX and Water-MATRIX, the Pinch Analysis software developed by the Process Systems Engineering Group, Department of Chemical Engineering, Universiti Teknologi Malaysia.

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