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# Comparison between pinch analysis and bridge analysis to retrofit the heat exchanger network of a kraft pulp mill

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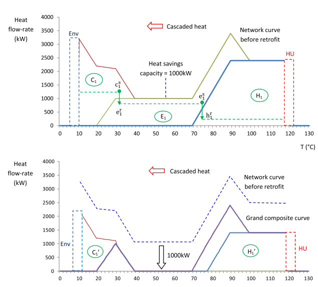
## HIGHLIGHTS

- Reducing the heat consumption implies decreasing the flow-rate of heat cascaded through the HEN.
- A bridge between cooler and heater is necessary to achieve heat savings in an existing HEN.
- Bridge analysis provides more information for network retrofit than pinch analysis does.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Pinch analysis is based on the hot, cold and grand composite curves and is the most commonly-used approach to identify strategies for reducing energy consumption by heat exchanger network retrofit. This method was originally developed for the synthesis of new networks, and there remain certain difficulties for its application to improve existing networks. The advanced composite curves have been developed for retrofit situations specifically, and use data about existing heat exchangers to provide more information about the modifications necessary to achieve heat savings. Bridge analysis, which is based on the energy transfer diagram, is a new method and enumerates the sets of heat transfer modifications necessary to save energy. In this paper, the grand composite curve, the advanced composite curves and the energy transfer diagram have been constructed for analysis of the heat exchanger network of a kraft pulp mill. Links between these methods are made explicit; then results are discussed and compared. It is shown that the information provided by these approaches is consistent; however, the level of detail progressively increases from the grand composite curve to the advanced composite curves until the energy transfer diagram. Fundamentally, reducing the energy consumption implies decreasing the flow rate of heat cascaded through the network from the hot utility until the environment. As a consequence, any heat savings solution includes network modifications bridging coolers to heaters. Traditional pinch analysis does not provide information about the network modifications required after removal of cross-pinch transfers, while the advanced composite curves indicate the heat savings potential attainable through modifications of few existing heat exchanger units. Bridge analysis provides more detail about heat savings modifications, which bridge existing heaters and coolers, than traditional pinch analysis and the advanced composite curves do.



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**Abbreviations and conventions**

| | |
|---|---|
| ACC | advanced composite curves |
| ACLC | actual cooling load curve |
| AHLC | actual heat load curve |
| AILC | actual internal load curve |
| $c_x^r$ | receptor of cooling system $C_x$ (environment) |
| $c_x^s$ | supplier of cooling system $C_x$ |
| CUC | cold utility curve |
| $C_x$ | cooling system $x$ |
| $E_y$ | internal heat exchanger $y$ |
| $e_y^r$ | receptor of internal heat exchanger $E_y$ |
| $e_y^s$ | supplier of internal heat exchanger $E_y$ |
| ECLC | extreme cooling load curve |
| EHLC | extreme heat load curve |
| EILC | extreme internal load curve |
| EMAT | exchanger minimum approach temperature |
| Env | environment |
| ETD | energy transfer diagram |
| FRAM | future resource-adapted mill, Swedish programme |
| GCC | grand composite curve |
| $H_z$ | heater $z$ |
| $h_z^r$ | receptor of heater $H_z$ |
| $h_z^s$ | supplier of heater $H_z$ (hot utility steam) |
| HEN | heat exchanger network |
| HRAT | heat recovery approach temperature |
| HU | hot utility |
| HUC | hot utility curve |
| TCLC | theoretical cooling load curve |
| THLC | theoretical heat load curve |
| TILC | theoretical internal load curve |

## 1. Introduction

Increasing energy costs and environmental concerns provide motivation for reducing the energy use in industry. Heat exchanger networks (HENs) play a significant role in industrial process energy systems. A high degree of heat recovery in the HEN is important for overall energy efficiency of the plant. By retrofitting existing HENs for improved heat recovery, utility consumption and thereby also energy costs are reduced.

Methods for energy analysis of existing heat exchanger networks (HEN retrofit) involve the identification and evaluation of inefficiencies in the current network, heat-saving modifications to reduce these inefficiencies, and the selection of the most promising modifications, i.e., the most profitable ones with acceptable operability. Methods for HEN retrofit can be broadly categorized into optimization-based approaches and insight-based approaches. The optimization-based methods for HEN retrofit can, in turn, be divided into deterministic and stochastic methods. The deterministic methods range from early developments by, e.g., Ciric and Floudas [11] and Yee and Grossmann [27] to more recent contributions by, e.g., Bjork and Nordman [5], Kralj [14], Nguyen et al. [18] and Zhang and Rangaiah [28]. One risk of using deterministic models is that they can be trapped in local optima. The stochastic methods (see, e.g., Athier et al. [2]; Bochenek and Jezowski [6]; Rezaei and Shafiei [21]; Wang et al. [26] are more likely to find the global optimum for HEN retrofits, but usually at the expense of long computation times even for small problems. The optimization-based methods are highly complex, and evaluation of the quality of solution may be difficult in practice considering possible trapping in local optimum and inevitable model and parameter uncertainties. Therefore, in practice, the insight-based approaches such as pinch analysis [16] are still the most widely used for industrial applications – also for retrofit (see, e.g., Asante and Zhu [1]; Tjoe and Linnhoff [23]). In pinch analysis, the insights from graphical tools such as composite curves are used to calculate energy targets. Heuristics are then applied for network design to achieve these targets.

The first complete method based on pinch technology for HEN retrofit targeting and design was presented by Tjoe and Linnhoff [23]. Their main point in the retrofit design is to eliminate heat transfer across the pinch by identifying and modifying heat exchangers in the existing HEN that exchange heat through the pinch. While the aim of the retrofit design method of Tjoe and Linnhoff [23] is to minimize the investment costs for a certain energy saving, the economic assumptions are largely based on grassroots design conditions.

In order to enable a more accurate representation of the costs involved in HEN retrofit, including costs such as costs for piping, pressure drops and area extensions of existing heat exchanger, the Matrix method [10] was developed. Also the Matrix method, which is based on the concepts of pinch analysis, aims at eliminating pinch violations. However, some relaxation of this requirement is allowed. The approach is iterative and based on heuristics.

Different approaches have been proposed in order to simplify or relax the HEN retrofit problem. For example, the so-called Path analysis was proposed by van Reisen et al. [24] as a way to reduce the complexity of the problem by decomposition and prescreening of the HEN before solution. An extension of the Path analysis called Structural targeting was presented a few years later [25].

Lakshmanan and Bañares-Alcántara [15] proposed a visualization tool called the retrofit thermodynamic diagram (RTD). The RTD is a modification of the conventional stream representation grid used in pinch analysis and allows for a graphical visualization of possible retrofit options.

The concept of network pinch was introduced by Asante and Zhu [1] based on the observation that heat recovery in a HEN is thermodynamically constrained by the network topology. The network pinch, unlike the process pinch, can be altered by modifications such as relocations or introductions of heat exchangers, or re-piping. The two-stage approach proposed by Asante and Zhu [1] makes use of the knowledge about the network pinch by starting with the identification of a modification that eliminates the network pinch. The approach relies on mathematical programming for the final optimization of the network design parameters. Hybrid methods combining pinch analysis and optimization have been proposed also by others (see, e.g., Briones and Kokossis [9]; Smith et al. [22]).

The main advantages of insight-based methods such as pinch analysis are their simplicity, their graphical representation, and the possibility of the design engineer to interact and influence the solution process. However, difficulties in data extraction, practical targeting and redesign of the network are still encountered using pinch analysis, not the least in retrofit situations.

In retrofitting, the existing equipment constrains the opportunities for cost-efficient integration. Consequently information about the existing heat exchanger network has to be included in the analysis. The advanced composite curves [19] which are based on the classical pinch curves, include information about the actual placement of heaters and coolers in the existing HEN. The advanced