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Utility Exchanger Network synthesis for Total Site Heat Integration

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ABSTRACT

Total Site Heat Integration (TSHI) targeting and optimisation methods have been well developed while few studies deal with detailed Utility Exchanger Network (UEN) design. The UEN is the network of heat exchangers that connect a site's centralised utility system to provide the required process heating and cooling while also facilitating inter-process heat recovery, i.e. TSHI. This paper presents a new UEN design procedure based on the recently developed Unified TSHI targeting method. The Unified method applies more strict constraints on the UEN network, compared to Conventional methods, allowing series utility exchanger matches for a non-isothermal utility if the exchangers in series are from the same process. This constraint reduces the dependency of the individual processes that constitute the Total Site. In UEN design procedure based on the Unified method, calculated utility targets can be archived after UEN design and the number of exchangers reduces compared to the Conventional methods' design procedure. Also, different Exchanger Minimum Approach Temperature in the UEN synthesis may have an influence on network design and the exchanger configuration but the identical heat recovery and utility targets are achieved after UEN design based on both design procedures.

1. Introduction

For the past forty years, Pinch Analysis (PA) has provided an elegant insight and graphical Process Integration (PI) technique for Heat Integration (HI) targeting and Heat Exchanger Network (HEN) design [1]. PA has been well-utilised in the process industry as a tool to increase Heat Recovery (HR) and energy saving and reducing overall energy demand and emissions within individual process units [2]. The aim of the HEN synthesis and design is to recover heat from the process by matching hot process streams and cold process streams to minimise the economic cost objective. After HR between hot and cold streams occurs, hot and cold utility are imported to supply any energy requirement for HEN. As it is shown in Fig. 1, a HEN for an industrial process may be considered to contain a Heat Recovery Network (HRN) with process-process heat exchanger matches and a Utility Exchanger Network (UEN) with process-utility matches. HRN refers to intra-process HI, which may be targeted, together with utility use, using PA.

Early HEN design based on PA was proposed by Tjoe and Linnhoff [3] to provide retrofit targets for utility consumption, and heat transfer area. However, in this method, the obtained area targets cannot reflect a complete area distribution within the HEN while obtained targets for grassroots design can satisfy area distribution within the HEN. The method was extended by Polly et al. [4] to take into account pressure drop constraints. Later, Zhu and Nie [5] considered pressure drop for HEN grassroots design. In their method, the pressure drop is considered at both targeting and design stages in a systematic manner.

Subsequent studies proposed methods to overcome many Pinch design method limitations. Shokoya and Kotjabasakis [6] developed an approach to integrate the area distribution for an existing HEN into the targeting stage. The technique proposed more realistic area targets compared to the technique developed by Tjoe and Linnhoff [3]. Cost matrix method for HEN retrofit was introduced by Carlsson et al. [7], who considered heat transfer area cost, equipment and pumping costs, and physical distance between the pair of streams. Akbarnia et al. [8] presented a different approach in PA considering piping costs in total cost targeting for HEN. A correlation of piping costs for individual streams was presented that includes factors such as pipe size, pressure rating, and construction material, i.e. heat exchanger cost plus piping cost, and consequently total cost. Jin et al. [9] combined PA and exergo-economic analysis

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Nomenclature

Roman

ΔT	temperature difference (°C)

Subscripts

cont	contribution
min	minimum
min(global)	global minimum

Abbreviations

BCC	Balanced Composite Curve
ChW	chilled water
CTST	Conventional Total Site Targeting
CW	cooling water EMAT Exchanger Minimum Approach Temperature HEN heat exchanger network
HI	Heat Integration
HPS	high pressure steam
HR	Heat Recovery
HRL	Neat Recovery Loop, HRN Heat Recovery Network
HTHW	high temperature hot water
ISCC	Interplant Shifted Composite Curves
LPS	low pressure steam
LTHW	low temperature hot water
MINLP	mixed integer non-linear programing
MP	Mathematical Programing
PA	Pinch Analysis
SCC	Shifted Composite Curve
TS	Total Site
TSHI	Total Site Heat Integration
TSST	Total Site Sensitivity Table
UEN	Utility Exchanger Network
UTSI	Unified Total Site Integration
UTST	Unified Total Site Targeting
VHPS	very high pressure steam

determining optimal minimum approach temperature for HEN synthesis. In this method, exergy consumption of heat transfer in HEN is calculated by integrating exergy differential elements on Balanced Composite Curves (BCC). For further HR and energy utilisation improvement of site-wide processes, integration between HEN and the central utility system have been considered in different cases such as integration of HEN with Organic Rankine Cycle [10], absorption cycle [11], trigeneration systems [12], and thermal membrane distillation systems [13].

One of the most important developments of PI is Total Site Heat Integration (TSHI) [14]. Dhole and Linnhoff [15] introduced the framework of a Total Site (TS) for large industrial sites that contain several distinct processes serviced by a central utility system that generates isothermal (e.g. steam) as well as non-isothermal (e.g. cooling water) hot or cold utility for use in the individual processes. After TSHI targets are set, the challenge is then to design a HEN that meets (or nearly meets) the TS utility and HR targets.

In early studies on conventional TSHI development by Raissi [16] and Klemeš et al. [17], minimal details on the synthesis and design of the UEN are presented. These case studies focused on using the steam system for TSHI. Since steam is isothermal, all utility exchangers can be arranged in a parallel structure to one another, which is simple network design. In recent years, the synthesis and optimisation of the HEN as the utility system have been considered by many researchers [18]. An improved Total Site Sensitivity Table (TSST) was proposed by Liew et al. [19] to be able to calculate the utility generation system's optimal size a design backup generators and piping system. Sun et al. [20] developed a graphical method based on extended Shifted Composite Curves (SCC) to calculate realistic TS utility targets accounting for boiler feedwater preheating, steam superheating, and desuperheating. Recently, Luo et al. [21] presented a simultaneous synthesis of the utility system

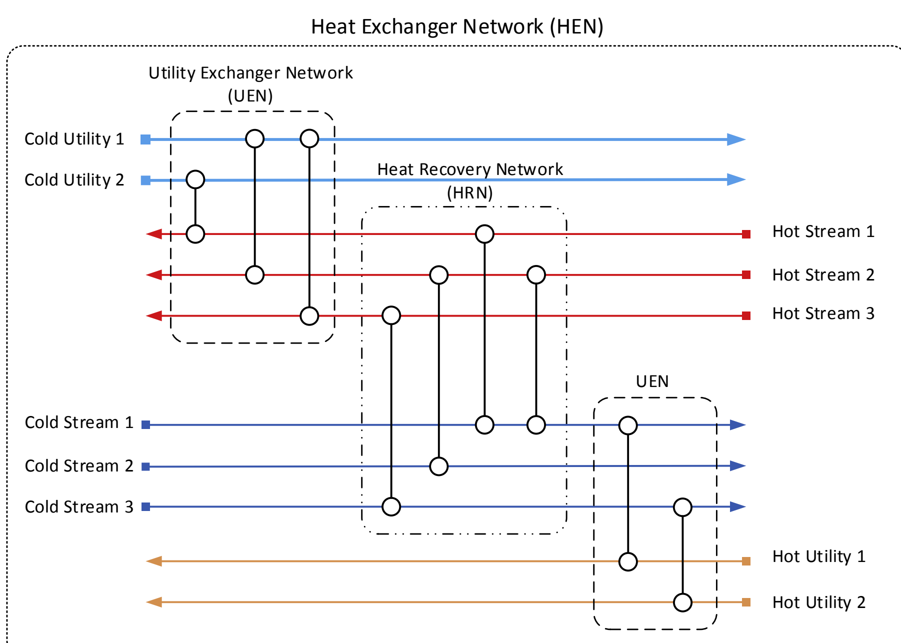

Fig. 1. A schematic of HEN containing HRN (process-process matches) and UEN (utility-process matches).