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A Unified Total Site Heat Integration targeting method for isothermal and non-isothermal utilities

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ABSTRACT

This paper presents a new unified Total Site Heat Integration (TSHI) targeting methodology that calculates improved TSHI targets for sites that requires isothermal (e.g. steam) and non-isothermal (e.g. hot water) utilities. The new method sums process level utility targets to form the basis of Total Site utility targets; whereas the conventional method uses Total Site Profiles based excess process heat deficits/surpluses to set Total Site targets. Using an improved targeting algorithm, the new method requires a utility to be supplied to and returned from each process at specified temperatures, which is critical when targeting non-isothermal utilities. Such a constraint is not inherent in the conventional method. The subtle changes in procedure from the conventional method means TSHI targets are generally lower but more realistic to achieve. Three industrial case studies representing a wide variety of processing industries, are targeted using the conventional and new TSHI methods, from which key learnings are found. In summary, the over-estimation of TSHI targets for the three case studies from using the conventional method compared to new method are 69% for a New Zealand Dairy Factory, 8% for the Södra Cell Värö Kraft Pulp Mill, and 12% for Petrochemical Complex.

1. Introduction

Process Integration (PI) has a key role in addressing energy efficiency and waste heat improvement in process industries [1]. There are three approaches to PI: (1) graphical methods including Pinch Analysis (PA), (2) Mathematical Programming (MP) methods, and (3) hybrid approaches [2]. Application of PI techniques to a wide variety of industries has helped realise meaningful increases in energy efficiency through improved process- and Total Site-level integration [3].

PA is an elegant insight and graphical technique for Heat Integration (HI) targeting and Heat Exchanger Network (HEN) design [4]. It has been well-utilised in the process industry as a tool to maximise energy saving and heat recovery within the individual process units [5]. An important strength of the PA approach to PI is the targeting stage where important performance targets are determined prior to the design stage. Establishment of meaningful and achievable targets provides critical guidance in the design stage to the engineer of the performance limitations and inherent compromises within a system. On the other hand, Mathematical Programing typically solves network superstructures to find feasible and optimal designs. MP combines algorithmic methods with fundamental design concepts [6]. It is capable of optimising both single- and multi-objective problems including HEN retrofit [7].

Total Site Heat Integration (TSHI) was initially introduced by Dhole and Linnhoff [8] to investigate HI across plants. TSHI is a strategy for the integration of large multi-process sites to improve site-wide energy efficiency that has focused on exploiting the steam utility system to recover and place heat [9]. The method prioritises integration of individual processes and zones (i.e. defined areas of integrity [10]), before integrating across an entire site using the utility system [11]. Total Site (TS) source and sink profiles are composites of shifted Grand Composite Curves (GCC)

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Nomenclature

Roman

CP	heat capacity flowrate (MW/°C)
H	enthalpy (MW)
Q	heat load (MW)
T	temperature (°C)
T^*	shifted temperature (°C)
T^{**}	double shifted temperature (°C)

Greek

Δ	difference between two states

Subscripts

cont	contribution
cont,P	contribution, process
cont,PS(i)	contribution, process streams for process i
cont,U	contribution, utility
cont,U(i)	contribution, utility for utility i
cont,US(i)	contribution, utility streams for utility i
j	utility counter
k	interval counter
m	counter for hot streams
min	minimum
min,P(i)	minimum process for each process i
min,PP(i)	minimum process to process for process i
min,PU(i)	minimum process to utility for process i
n	counter for cold streams
s	supply
t	target

Abbreviations

CC	Composite Curves
ChW	chilled water
CTST	Conventional Total Site Targeting
CW	cooling water
GCC	Grand Composite Curve
HI	Heat Integration
HEN	heat exchanger network
HOL	hot oil loop
HPS	high pressure steam
HRL	Heat Recovery Loop
HTHW	high temperature hot water
LPS	low pressure steam
LTHW	low temperature hot water
MP	Mathematical Programing
MPS	medium pressure steam
PA	Pinch Analysis
PI	Process Integration
PT	Problem Table
SUGCC	Site Utility Grand Composite Curve
TS	Total Site
TSHI	Total Site Heat Integration
TSP	Total Site Profile
TW	tempered water
UTST	Unified Total Site Targeting
VHPS	very high pressure steam

from individual processes and applied to calculate TS targets for heat recovery, utility use, and shaft work/power generation [12]. Shortly after its initial development, Klemeš et al. [9] summarised successful applications of TSHI to an acrylic polymer manufacturing plant, several oil refineries and a tissue paper mill, which all showed utility savings between 20 and 30%. The PhD thesis of Raissi [13] presents much of the early developments of TSHI.

Inter-process integration through TSHI has recently led to increasing utility savings in slaughter and meat processing by 35% [14], large industrial parks in Japan about 53% [15] and Thailand by 28% [16], chemical processing clusters by 42% [17], and Kraft pulp mills about 13% [18]. Notable developments to the TSHI method include: temperature shifting using process [19] and stream [20] specific minimum approach temperatures, application to Locally Integrated Energy Sectors [21], integration of renewables [22], variable energy supply and demand system [23], heat exchange restrictions [24], seasonal energy availability [25], centralised utility system planning [26], retrofit investigations in TS [27], process modifications [28], minimisation of thermal oil flowrate in hot oil loops [29], heat transfer enhancement in site level heat recovery systems [30], variable energy availability [31], and TS utility system targeting [32]. There are also MP approaches to TSHI [33] including its retrofit [34].

Effectively applying TSHI techniques to processing applications and sites that required non-isothermal utilities is complex and economically challenging. The use of a Heat Recovery Loop (HRL) for site-wide heat integration of low temperature processes was investigated by Atkins et al. [35] and later formalised into a comprehensive method by Walmsley et al. [36]. In their work detailed targeting and design considerations for HRLs have included: thermal storage management [37], storage temperature selection [38], storage capacity [35], heat exchanger area sizing method [39] and performance [40], the integration of industrial solar [41], and the effect of using a nanofluid as the intermediate fluid on heat recovery [42]. Recently, Chang et al. presented the use of MINLP model with economic objectives to optimise HRLs [43].

Liew et al. [44] introduced an algebraic TS energy targeting methodology using cascade analysis. This methodology is developed mainly for targeting isothermal utilities. Non-isothermal utility (e.g. hot water and cooling water) were considered in the grassroots design [44], retrofit [27], and with variable supply and demand [31] case studies by considering only a utility supply temperature and no fixed utility target temperature. This assumption at times generates misleading energy targets for non-isothermal utility because there is no guarantee that the consumption and generation of the non-isothermal utility will maximise heat recovery. Methodology improvement, such as a targeting algorithm for non-isothermal utility, is therefore needed to systematically consider non-isothermal utility with fixed or soft target temperature.

TSHI methodologies are baseline feasibility studies for maximum energy recovery via heat exchanger and utility network. However, there are no network constraints (besides thermodynamics) in conventional TSHI for heat exchanger matches between process and utility streams. This problem was recently recognised by Sun et al. [32]. As the boiler feed water (non-isothermal utility) pinched against the TSP, they recognised that the heat may need to be transferred from multiple processes and that the network, although thermodynamically feasible, might be too complex in practice [32]. Conventional TSHI allows process-utility heat exchanger matches in series from any process for the utility to reach its target temperature and then returned to the central utility system. As a result, conventional TSHI targets for non-isothermal utilities can be overly optimistic. The HRL method, on the other