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Total Site Heat Integration planning and design for industrial, urban and renewable systems

Peng Yen Liew [a,b], Wai Lip Theo [c], Sharifah Rafidah Wan Alwi [a,c,*], Jeng Shiun Lim [a,c], Zainuddin Abdul Manan [a,c], Jiří Jaromír Klemeš [d], Petar Sabev Varbanov [d]

[a] *Process Systems Engineering Centre (PROSPECT), Research Institute of Sustainable Environment (RISE), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b] *Department of Environmental Engineering and Green Technology, Malaysia – Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, 54100 Kuala Lumpur, Malaysia*
[c] *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[d] *Faculty of Information Technology and Bionics, Pázmány Péter Catholic University, Práter u. 50/a, 1083 Budapest, Hungary*

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ABSTRACT

There has been growing interest in developing Locally Integrated Energy Sectors (LIES) as a Process (Heat) Integration approach for synergising the industrial thermal energy systems that include renewable energy resources with urban (i.e. civic, residential, business and service complexes). The aim is to enhance the regional energy efficiency and minimise greenhouse gas (including carbon) emissions. However, a comprehensive planning and design framework is crucial at the onset of its development, which is accounting for supply and demand sides, but there have been limited works directed to this scope to date. For the development of such framework, this paper reviews the energy consumption targeting methodologies via Total Site Heat Integration for estimating and designing the capacity of the utility have been reviewed in this work, inclusive of both insight-based Pinch Analysis and mathematical modelling approaches. As a final outcome of the review, suggestions are provided for investigating key factors for integration of industrial, residential, commercial, institutional and service energy systems, maximising the integration and reuse of waste and low potential heat, including renewables to boost sustainability aspects. The review of methodologies for energy system integration is followed by identification of research directions that deserve future attention, refinement and development.

Contents

* Corresponding author.
E-mail address: shasha@cheme.utm.my (S.R. Wan Alwi).

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1. Introduction

Process Integration (PI) as one of the methodologies for energy saving and pollution reduction, has been studied extensively for resource conservation for more than forty years [1]. PI has been initially developed for aiding decision makers on the possible heat savings by reusing waste heat. It has been further extended with an important implementation in the mitigation of GHG emissions, and in solutions for environmental and sustainability issues [2]. Heat Integration is the earliest PI methodology, which has been introduced for minimising industrial energy consumption during the energy crisis in 1970s [3]. The concept has been widely used in processing and power generation industries. In performing PI, Mathematical Programming and Pinch Analysis are among the most popular approaches used [4].

Heat Pinch Analysis comprises systematic thermodynamically based approach for exploring and optimising energy recovery opportunities between heat sources and heat sinks, which is able to reduce the external hot and cold utility usage. Besides Heat Pinch Analysis, the Pinch concept has been extended to hybrid power systems [5], which involves integrating renewable energy into a commercial power system aimed at reducing the non-renewable energy sources. The Pinch Analysis concept has also been applied in the context of other resources, including for decentralised electricity generation [6], CO_2 emission [7], carbon emissions constrained energy planning [8], carbon emission planning [9], cogeneration and waste [10], mass [11], water [12], gas [13], production planning [14], supply chain [15] and property [16].

Klemeš et al. [1] reviewed the forty years development of Heat Integration through Pinch Analysis and mathematical programming until 2012. In another paper, Klemeš et al. [4] summarised the recent developments of Process Integration. As an insight-based tool, Pinch Analysis provides the advantage for users to visualise the saving potentials and modifications required in a process, which is favourable for engineers and decision makers. Mathematical Programming approaches have also been widely used in the field of Process Integration, due to its capability of solving multi-objectives problems. In recent years, research on Total Site Heat Integration (TSHI) involving inter-process heat recovery that include low-grade waste heat and integration of renewable energy sources has received substantial attention, along the line of both the insight-based as well as the mathematical programming approaches. This can be seen by the growing number of research publications, research teams involved, and industrial implementations associated with TSHI.

This paper reviews the state-of-the-art on the targeting methodology for inter-process heat recovery using Heat Pinch Analysis and mathematical programming approaches in the field of Process Integration. This paper provides an overview of the current TSHI methodologies for integrating urban and renewable energy to LIES. It then discusses the challenges for integrating industrial, urban and renewable energy system from the sustainability point of view. The potential for the future research directions for heat generation and distribution planning as well as the associated design tools and methodologies are highlighted.

2. Overview of Total Site/utility system configuration

Single process Heat Integration using Pinch Analysis [17] has been extended to examine the energy recovery potential between industrial processes by Dhole et al. [18] and further developed by Klemeš et al. [19], known as Total Site Heat Integration (TSHI). Site Utility System (e.g. steam, hot oil and hot water) serves as the heat transfer medium for recovering energy between processes. Heat excess from a process can be transferred to a utility system for the purpose of generating steam or heating hot oil or heating water. The utility stream generated in this way can be further used by another process to satisfy the energy demand.

Fig. 1 illustrates the relationship between processes, condensate, and steam at different pressures [20]. The site steam system in this example has three different levels, which are High Pressure Steam (HPS), Medium Pressure Steam (MPS) and Low Pressure Steam (LPS). A process with excess heat source generates steam for steam header. The generated steam is then used for satisfying the heat sinks at other processes. If the process heat sources are not able to satisfy the process heat sink, boiler steam generation is considered for fulfilling the site total energy demand. The boiler steam generation has typically higher quality (steam temperature and pressure) than the required quality by the process. Steam turbine can be used to reduce the pressure of the steam and simultaneously generate electricity for operating other electrical equipment on site. The steam turbine can be either be a condensing steam turbine, or a back-pressure steam turbine, and there can be intermediate extraction points. Steam can be extracted from the turbine at different pressure levels. Steam consumed by process heat sinks is returned to the de-aerator as condensate. The condensate is treated in the de-aerator and exits as boiler feed water for fuel boiler and process boilers. The remaining cooling demands/excess energy are cooled by the Cooling Water (CW) system in the site utility system.

TSHI was first introduced for the purpose of maximising thermal energy saving via the integration of industrial processes. The concept has been further extended to include renewable energy sources as well as to consider other sources and consumers as site processes – e.g. leisure and commercial buildings. This conceptual extension is known as Locally Integrated Energy Sector (LIES) [21]. The structure of LIES is as shown in Fig. 2. Kwak et al. [22] analysed four types of low grade heat utilisation technologies for a TS system. The work concluded that Organic Rankine Cycle is a promising technology during winter time, while boiler feed water heating is found to be the best solution within the study during summer, for recovering low grade heat in process industry. The energy availability and the storage