Applied Thermal Engineering 70 (2014) 1073–1083

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Algorithmic targeting for Total Site Heat Integration with variable energy supply/demand

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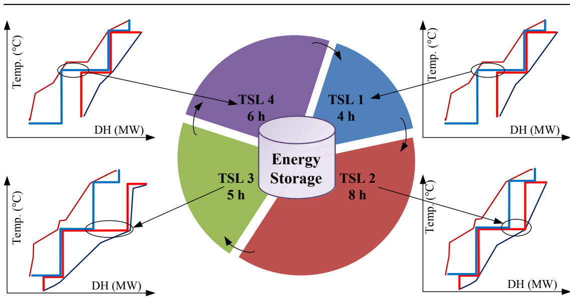
GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 December 2013
Received in revised form
11 February 2014
Accepted 5 March 2014
Available online 15 March 2014

Keywords:
Total Site Heat Integration
Thermo-chemical heat storage
Heat loss
Utility system
Pinch Analysis
Cascade analysis
Variable supply and demand

ABSTRACT

Fluctuating renewable energy supply presents a challenge for applying energy-saving methodologies such as Process Integration. Graphical targeting procedures based on the Time Slices (TSLs) have been proposed in previous works to handle the energy supply/demand variability in TSHI. The targeting procedures for TSHI with TSLs include the construction of Composite Curves, Grand Composite Curve and Total Site Profile for each time interval. Heat Integration analysis utilising a numerical algorithm typically offers higher precision and more rapid calculations as compared to the graphical approach. This paper introduces an algorithm to efficiently perform utility targeting for a large-scale TSHI system involving renewable energy and variable energy supply/demand to include TSL. The presented tool is an extension of the Total Site Problem Table Algorithm (TS-PTA), which has been previously used for processes with steady energy supply/demand. Due to its algorithmic nature, the technique presented enables the accurate and rapid determination of the stream origins, and can be embedded into larger algorithms. Optimised heat storage facilities are used to manage the variable energy supply and demand. The Total Site Heat Storage Cascade (TS-HSC) is the core of the algorithm. The new developed tool is incorporated with the heat losses for the thermo-chemical energy storage systems. The process start-up and continuous operations are considered in the novel methodology. The tool is featured to analyse the heat excess in specific TSLs that can be cascaded to the next TSL via energy storage system during start-up and operation. The proposed tool can be also used to estimate the required heat storage capacity.

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http://dx.doi.org/10.1016/j.applthermaleng.2014.03.014
1359-4311/

1. Introduction

Widespread utilisation of renewable energy sources can help to reduce the dependency on fossil fuels and mitigate the environmental emissions. However, renewable energy has been mostly utilised for power generation and for buildings. It has been targeted that 21% of the energy feedstock for the manufacturing industry by the year 2050 to comprise of renewable energy [1]. In order to meet this target, more research emphasis needs to be given to the use of renewable energy in the industrial sector. The Pinch Analysis is an established tool for Heat and Power Integration to reduce the energy usage in the industry [2]. By maximising the heat recovery within processes, Heat Integration minimises the energy requirement and reduces the wasted energy as well as environmental emissions [3].

The Heat Pinch Analysis tool has been extended to consider energy integration across several plants or processes using indirect heat transfer [4], termed as Total Site Heat Integration (TSHI). The methodology has been extended by Raissi [5] and developed further by Klemeš et al. [6]. The established tools involved in the analysis include the Grand Composite Curves (GCC), the Total Site Profiles (TSP), the Site Composite Curves (SCC), and the Site Utility Grand Composite Curves (SUGCC). These tools have been developed to enable visualisation of the heat availability and consumptions on the TS. Varbanov et al. [7] proposed to replace the global minimum temperature difference (ΔT_{min}) with the minimum temperature difference for process to process ($\Delta T_{min,pp}$) and for utility to process ($\Delta T_{min,up}$) in Heat Integration analysis. Numerical algorithms have been introduced for TS analysis by Liew et al. [8]. The numerical tools, such as the Total Site Problem Table Algorithm (TS-PTA), the Multiple Utility Problem Table Algorithm (MU-PTA), and the Total Site Utility Distribution (TSUD) table, have been extended from the graphical approaches. Total Site Sensitivity Table (TSST) is proposed by Liew et al. [9] for assessing the utility requirement sensitivity towards the process operational changes. The algebraic/algorithmic approach vitally complements the graphical approaches as it can provide an efficient base algorithm for site-wide utility targeting, pinch point determination and even network design (covering single, multiple and total site process as well as utility systems).

Kapil et al. [10] introduced a mathematical optimisation method for integrating the low grade heat to satisfy the district heating requirement. Hackl and Harvey [11] applied the TS analysis and exergy analysis on a sub-ambient refrigeration system. Hackl et al. [12] analysed the TS energy integration of a chemical cluster in Sweden. The cluster consists of five chemical companies producing a variety of products, including polyethylene, polyvinyl chloride, amines, ethylene, oxygen/nitrogen and plasticisers. The TS analysis result shows that up to 129 MW of energy can be potentially saved via TS centralised utility system. The TS methodology also has been implemented to heavy chemical complex [13], steel plant [14], and large dairy factory [15]. Varghese and Bandyopadhyay [16] proposed a systematic methodology for integrating the fired heater into the site utility system. A new model for estimating the cogeneration potential in a site utility system is published by Khoshgoftar Manesh et al. [17]. Chaturvedi and Bandyopadhyay [18] proposed a new targeting methodology using indirect heat transfer in TS integration for batch processes. Chew et al. [19] summarised the issues to be considered to ensure the practical industrial application of TS system.

The TS concept was initially proposed as a systematic tool for energy conservation among industrial processes. The Locally Integrated Energy System (LIES) is a TS problem addressed by Perry et al. [20] where batch processes, renewable energy and urban energy consumptions are considered. Varbanov and Klemeš [21] proposed a TS heat cascade, which has shown the relation between process, steam system, renewable energy and heat storage. However, the intermittent renewable energy sources (e.g. solar for heat generation) typically varies with time and location [22]. Similar to the methodology for individual Batch Process Heat Integration, the Time Slice (TSL) methodology is introduced to handle the variable nature of the renewable energy supply and urban energy demands [21].

Fluctuations in energy supply/demand in a TS system are addressed by installing a Thermal Energy Storage (TES) facility and by implementing the TSL methodology in the system. The concept of TS energy consumption and generation can be understood from the perspective of a centralised utility system. Fig. 1 shows the TS Heat Cascade proposed by Varbanov and Klemeš [21]. TSP targets multiple utility requirements, which are indicated by black arrows in Fig. 1 as steam generation and consumption. Heat storage facilities can be available for any type of utility, represented by horizontal arrows. The storage systems connect the utility from one TSL to another. The heat excess within a cycle of operation has to be discarded to prevent the waste of energy, which cannot be accumulated in the system. It is important to maintain the energy storage facility capacity at the optimal condition.

Three types of TES facility among those available are: the sensible heat, latent heat, and chemical energy storage systems [23]. The energy capacity and storage volume depends on the material and temperature. Sensible heat storage is based on liquid media storage (e.g., water, oil-based fluids, and molten salts) or solid media storage (e.g., rocks and metal) [24]. Latent heat storage is more attractive compared to sensible heat storage because it requires less material weight and volume to store a certain amount of energy. Latent heat also requires large heat storage densities and capacities at constant temperatures. Numerous studies on latent heat storage materials, also known as phase change materials, have been reported. Phase change materials can be organic or inorganic depending on their temperature range, suitability for heating or cooling, thermophysical properties and long term stability [25]. The energy density provided by thermo-chemical storage systems is significantly higher than that of other storage technologies; as such, this system requires additional studies [26]. The high energy density of reversible chemical reactions/processes encounter the problem for other types of energy storage facility: a very large volume of media is required to store a certain amount of energy [27].

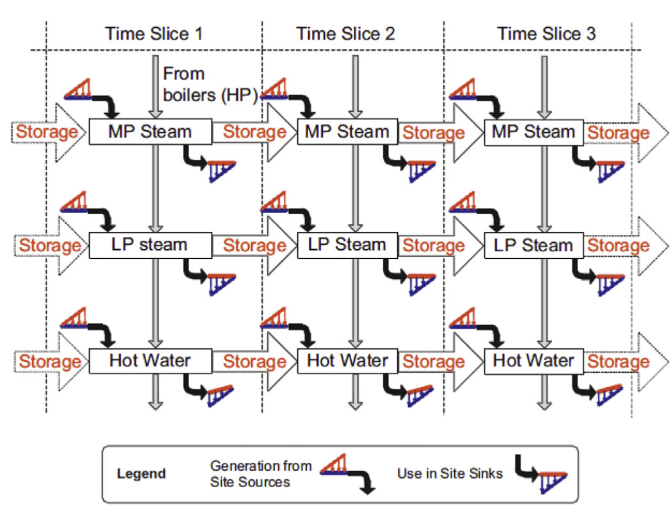

Fig. 1. Total Site Heat Cascade [21].