Renewable and Sustainable Energy Reviews 98 (2018) 439–468

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

New directions in the implementation of Pinch Methodology (PM)

Jiří Jaromír Klemeš, Petar Sabev Varbanov*, Timothy G. Walmsley, Xuexiu Jia

Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology – VUT Brno, Technická 2896/2, 616 69 Brno, Czech Republic

ARTICLE INFO

Keywords:
Pinch Analysis
Process Integration
Problem Table
Composite Curves
Energy and Water Saving
Emissions Targeting and Reductions
Total Site
Site Profiles

ABSTRACT

The emergence of Pinch Analysis from more than four decades ago opened a new area of intense research development that has even accelerated in recent years. Initially, Pinch Analysis (PA) provided a systematic thermodynamic-based approach to address the need for large energy savings around the 1970s oil crises. Since inception, the Pinch Methodology (PM) has flourished considerably, finding meaningful application to a wide range of industrial, regional, and global challenges well beyond heat – it's most well-known and first application. This review represents an attempt to identify and substantiate future directions of research for the most significant implementations of Pinch Methodology. Reported applications in the literature range from Heat Integration, Total Site and Water Integration through to Emergy and even Financial Investment Planning; cutting across multiple engineering fields – Mechanical, Chemical, Process, Power, and Environmental Engineering – as well as entering the research domains of Management and Finance. Key findings of this review include: (1) the need for more awareness within the engineering and science research communities of the latest and continuing developments of the Pinch Methodology; (2) a need for complete tool sets covering targeting through to engineering design for many of the Pinch Methodology applications; and, (3) the full benefits of Pinch Methodology can only be achieved in developing design solutions with an appreciation for the most recent developments.

1. Introduction

Pinch Analysis (PA) originates from systematic efforts to improve heat recovery in the industry through Process Integration (PI) [1]. Since early 1970 of the last century, the impetus for solving energy-related issues has been always present, as can be witnessed by analyses focused on specific industries – such as steel, petroleum processing [2] and economy-wide studies – e.g. the USA analysis [3] – and the corresponding original diagram data for many countries [4]. On the same website can also be found a little older statistical data on the combination of water and energy use, as well as on GHG emissions (sometimes referred to incorrectly as "Carbon"). Similarly, the analysis of global virtual water flows [5] raised the awareness of the increased water-related issues starting from the water footprints of production/consumption of goods and their relation to the international trade.

All these issues, continuously evolving, have stimulated the further development and expansion of the Pinch Methodology (PM). The PM has been developing since then and, in recent years, the developments have accelerated. This review comprises an effort to collect, assess and overview the recent trends and indicate the possible directions for the future developments.

1.1. Previous reviews of Pinch Methodology and Process Integration

Since the emergence of PM, there have been several reviews by various teams. Some of the older reviews include: Dunn and El-Halwagi [6] emphasising Mass Integration and the more general review on green supply chains by Srivastava [7], where the Pinch Method is mentioned as one of the approaches, inspiring resource-saving optimisation. Foo [8] performed a review of the state-of-the-art of Pinch Methods confined to the area of Water Network Synthesis. The analysis concerned flow rate targeting techniques for water reuse networks, as well as for wastewater treatment, followed by a review of the network design techniques.

A significant review on Process Integration (PI) [9] was published in 2013. This review presents a comprehensive critique of the thermal-related PM developments, water network methods and touching on other developments in the areas of supply chains and mass exchange. The paper attempts a systematic analysis of PI methods, comparing the strong and weak points of the conceptual and mathematical programming-based approaches, limited to the studies available at the beginning of 2013. More recently, Foo and Tan [10] analysed studies that applied PM to environmental footprint and emission problems.

* Corresponding author.
E-mail address: varbanov@fme.vutbr.cz (P.S. Varbanov).

https://doi.org/10.1016/j.rser.2018.09.030

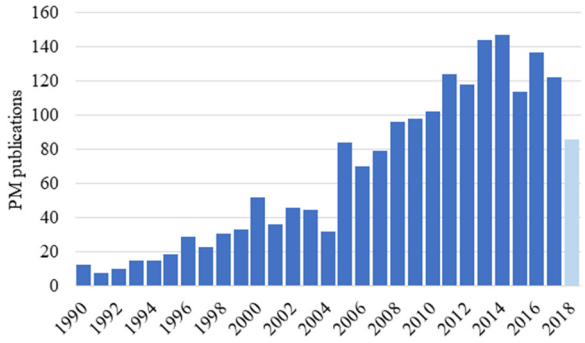

Fig. 1. Publications on PM indexed by Scopus [12] since 1990. Note, the statistics are non-exact as many Pinch focused papers been published under Process Integration, Heat Integration, etc., which overlap with non-Pinch approaches.

Similarly, Manan et al. [11] focused on the contribution of PI to CO_2 emission reduction and re-use. These two reviews are comparatively much narrower in scope compared to the current undertaking.

The current review provides a comprehensive analysis of the PM developments since 2013. Its breadth reaches across the most relevant and significant research PM areas related to resource and energy use minimisation. One of the distinguishing features of this review is its in-depth analysis of the Pinch methodological advancements including the origin, recent follow-up developments, implementations and case studies, as well as suggesting cohesive directions for future research. Fig. 1 further supports the need for a comprehensive review on recent developments with more than 360 papers published since the beginning of 2013.

1.2. The aim of the review

The Pinch Methodology has been developing for more than 40 y [13]. This has led to numerous original research papers and also frequent reviews, comprehensive books, guidebooks and textbooks. The developments, originating from Europe and America, have been further accelerating with the growing involvement of strong research groups from South East Asia and China. The geographical spread underlines the importance of frequent reviews to support a cross-fertilisation of ideas and to unify the terminology used by various teams. This has been also supported by annual conferences on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction (PRES) [14], already having two-decades of productive history [15] from which have regularly originated Special Issues of several strong journals such as the recent issue in the Journal of Cleaner Production [16].

An important trend has been widespread in the areas and applications to which Pinch concepts have been applied [9]. While the origin focused on Process Integration for saving process heat, fuels, water and wastewater, the more recent developments have propagated to many more areas, even touching such domains as supply chains, production planning, and regional development. The developments succeed to a different degree to implement the Process Integration philosophy of obtaining targets before detailed process modelling and optimisation of the design, retrofit or operation [13].

The present review aims at analysing the more recent developments in the light of the core Pinch Analysis applications and in the context of their applicability to new problem domains. The main analysis criteria include the following [17]:

- Fulfilment of the main aims and goals of PA of obtaining performance goals before process optimisation (e.g. design)
- Efficient visualisation and inter-stakeholder communication in solving the underlying problems.
- Generation and revealing of insights about the analysed problems
- Using the analogy with the originally developed PA for Heat Integration (HI) to as many as possible generic implementations.

In analysing the published works, the following goals are pursued: identification of the various perspectives on PM, potential improvements to existing PMs.

1.2.1. Investigate different perspectives of PM implementing targeting largely water/wastewater and greenhouse gas emissions

The Pinch Methodology started with Heat Integration and reached in this field the most comprehensive range of practical applications. Those have been covered extensively by high-quality books, among which are the prominent “red-book” user guide [18], an extensive Handbook of Process Integration [19], and integrated coverage within Chemical Process Design book [20]. However, after some years of intensive research, researchers recognised that the strength of the PM can beneficially apply to other research areas. The first developments using the analogical approach with heat were developed for mass exchange [21], and related water and wastewater minimisation [22]. With the growing awareness of the need for sustainability, cleaner production and environmental protection, an analogy of Heat Integration Pinch has been developed to target the minimum CO_2 and other greenhouse emissions, and these developments have been considerably flourishing.

1.2.2. Identify what PM development can potentially provide in the future

One of the challenges of each credible review paper is to judge and suggest the future developments in two-directions – deepening the existing implementations and extending them into new fields. This has been one of the primary tasks of the present review paper.

1.2.3. Find out the research gaps and potential applications and future of PM implementation

The research gaps should be sought as potential new areas for applying the Pinch idea, as well as in identifying missing parts of the full PM set of tools: plots, numerical cascades, identification of targets, problem decomposition and guidance to an optimal design. Another potential for research gaps should be the expansion of the problem types solved by PI and PM variants. For Heat Exchanger Networks, a comprehensive set of commercial and public domain tools exist for synthesis, retrofit and operation optimisation, supplemented by minor improvements like integration with Heat Transfer Enhancement, already exist and continue to be refined. This is not the case for many of the other PM avenues – including Total Site Integration (TSI), Utility System optimisation, Water Networks Integration and some others.

1.2.4. How to improve the existing Process Integration methods

Potential improvements to existing PI methods is also important. Since the inception of PI in the form of Heat Integration, it has become clear that these are not alternatives with Mathematical Programming and other modelling and optimisation techniques. These different approaches should rather be employed in synergy. This has been the lesson from one of the most successful methods for Heat Exchanger Network Synthesis based on Block Decomposition [23].

2. A brief history of Pinch Methodology (PM) from the 1970s to 2000

The history of the Pinch Methodology has been described in several reviews and books. However, as many authors have not been personally involved in the early development, it is perhaps useful to provide at least a short recapitulation, using the information from the Handbook of Process Integration [19], where is also possible to find a more comprehensive description of the Pinch history including the important developments that played out, first at the Chemical Engineering Department of the University of Leeds, UK and later especially at the Centre (Department) for Process Integration at UMIST, Manchester, UK.