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Review of the corrected PhD Thesis by Mr. Jun Yow Yong

Title:

Tools and Methods in Aiding Heat Exchanger Network Retrofit for Better Economic Performance

I have evaluated the corrected PhD Thesis, as submitted on 12.09.2018. The candidate has made appropriate improvements. Detailed analysis of the thesis follows.

1. Scope of the thesis

Mr. Jun Yow Yong has prepared his thesis at the Doctoral School of Information Science and Technology, University of Pannonia under the supervision of Prof. Jiří Jaromír Klemeš and Dr Petar Sabev Varbnanov.

The subject of the thesis is the development of tools for visual and numerical assistance in decision making for retrofit of Heat Exchanger Networks (HENs), with the aim of improving economic performance. The thesis has three main parts, relating to the workflow in HEN retrofit – data acquisition and reconciliation, identification of structural retrofit options and selection of economically-viable retrofit actions. The data acquisition part concerns data collection and reconciliation for HENs and Site Utility Systems, using an iterative method with a simple user interface and lower computational requirements. The part dealing with the identification of HEN retrofit options offers the Shifted Retrofit Thermodynamic Grid Diagram – representing the HEN topology with superimposed temperatures and heat-capacity flowrates of the heat exchange matches. This is complemented by a matrix form, to achieve scalability of the representation. The final part consists of the method for identifying utility generation and sales options to replace direct improvement of the heat recovery inside the HEN, which require lower investment and generate revenue.

2. Structure of the thesis

The structure of the thesis consists of an introduction, description of the research goals, presentations of the iterative data reconciliation method, the HEN retrofit visualisation and representations – the Shifted Retrofit Thermodynamic Grid Diagram and the Heat Exchanger Network Stream Matrix, and the section on HEN modification for waste heat utilisation. The thesis is concluded with sections on summarising the scientific contributions and conclusion. The thesis is well-structured and is generally easy to follow. The related research work has been well presented. The English language is appropriate.

3. Publications related to the thesis

The work has already been published in 4 papers in international journals with high impact factors and in 6 conference papers. His two most cited papers have been increasingly cited, reaching 52 and 13 independent citations each, while the total of the independent citations to Mr Yong's publications has increased to 94, according to Scopus (09.01.2019). His most cited paper has been classified by WoS (56 citations) as Highly Cited Paper, which is reserved for 1 % of top-cited papers.

4. Reviews of chapters

4.1. Chapter 1: Introduction

The first chapter provides an introduction to the overall problem and its background. The HEN targeting and design methods are briefly summarised, which is followed by the reasoning why HEN retrofit is an equally important task. The state of the art in HEN retrofit is presented, including network representation, modelling and solution methods, as well as those for data acquisition.

4.2. Chapter 2: Research Goals

In the second chapter, the state of the art, reviewed previously, is analysed. The research goals of the current thesis are identified and assigned to further chapters of the thesis.

4.3. Chapter 3: Iterative Method for Data Reconciliation on Energy System

This chapter presents the Data Reconciliation method, tailored to HENs, developed in the thesis. The presented method overcomes the non-linearity of the model constraints by applying an iterative algorithm for solving it. It defines two linear sub-models, where the stream temperatures and the flowrates are considered as fixed parameters during the optimisation rounds, and the models are applied in alternate steps, iteratively. The provided case studies demonstrate achieving acceptable accuracy at a very low computational burden. The method has been analysed for applicability to a wider set of HENs, and a limitation has been revealed and remedied. The chapter concludes with an extension of the data reconciliation method to the Total Site utility systems.

4.4. Chapter 4: Advanced Visualisation for Retrofitting Heat Exchanger Network in Heat Integration

This chapter describes the definition and use of two HEN visualisation tools and their application to HEN retrofit – the Shifted Retrofit Thermodynamic Grid Diagram (SRTGD) and the Heat Exchanger Network Stream Matrix (HENSM). SRTGD shows in the same picture heat capacity flow-rates (CPs), temperatures and the topology, allowing the engineers to simultaneously account for these factors. This representation allows to easily identify Process Pinches and Network Pinches and potentially feasible

heat recovery paths through the HEN. It has been demonstrated that the SRTGD is capable of screening feasible from infeasible solutions, which provides the decision maker with information to construct favourable paths adding key heat exchange matches. In turn, the HENSM does not require graphical illustration to contain the stream information and connection. It allows performing the described analysis in a matrix and offers important scalability.

4.5. Chapter 5: Heat Exchanger Network Modification for Waste Heat Utilisation

The fifth chapter solves the problem of finding an alternative to retrofit for increased internal recovery in HENs when the possible options for that are too complicated and costly. The chapter provides the reasoning for selecting a suitable heat valorisation goal and designing an additional HEN section for generating a utility stream to be sold for revenue. In the provided case study, the HEN is modified to generate hot water from the waste heat streams. The considered example is from a small crude oil refinery, operating under four periods within the annual cycle. The designed HEN with heat valorisation caters for all four scenarios.

4.6. Chapter 6: Novel Scientific Developments in the Current Thesis

This is an important chapter, summarising the research contributions of the thesis. The chapter briefly outlines each of the contribution groups:

- The iterative method for data reconciliation, achieving good accuracy at reduced computational loads
- The SRTGD and the HENSM, allowing efficient path construction and retrofit paths analysis
- The waste heat utilisation for utility generation, allowing to simultaneously achieve reduced investment and revenue via the utility generation.
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4.7. Chapter 7: Conclusions

In the conclusion chapter, the scientific results are summarised more elaborately, also analysing the possible ways of developing further the described methods.

5. Analysis of the raised issues from the initial review

5.1. Issue 1: In Chapter 2, the state-of-the-art analysis is integrated within the formulations of each of the paper goals. While this is convenient for seeing the relevance of each paper goal, it looks more like a justification of already selected goals. To avoid this issue, it is recommended to provide in this chapter a proper state-of-the-art analysis, followed by the formulation of the research goals.

Comments on the revision: In Chapter "2. Research Goals", an analysis has been added of the overall workflow and state-of-the-art, complementing the review from Chapter "1. Introduction". Now Chapter 2 provides appropriate reader guidance.

5.2. Issue 2: In Chapter 3 the methods are well described, but the chapter can benefit from an elaboration of the data reconciliation context – to include a diagram of the procedure of plant data acquisition and processing, of which the reconciliation is only a part.

Comments on the revision: The data processing workflow has been clarified in Appendix 2.

5.3. Issue 3: In Chapter 4 – adding grid lines to the entries in Table 4.5, which have values, would help to trace the topology better.

Comments on the revision: The requested correction has been made appropriately.

5.4. Issue 4: In Chapter 5, there seems to be a technical issue with cross-referencing tables – there is a reference to "Table 4". It looks like this is a cross-reference to Table 5.7. Please double check and correct.

6. **Comments on the revision:** The cross-references in Chapter 5 seem correct now.

7. Summary

The goals of the thesis have been well selected, based on a thorough state of the art analysis and consideration of the relevance to practical engineering applications. It can be concluded that the proposed concepts and methods have been being correctly formulated and that the objectives of the thesis have been achieved. Overall, the PhD thesis is well written and contains original contributions to the science.

The candidate has a very high quality of publications related to the topic of the thesis. To this testifies the high number of citations.

On the basis of above said I do recommend granting the PhD degree to Jun Yow Yong, subject to the minor improvements described above and the successful defence of her thesis work and suggest "summa cum laude" award.

Prof. Ing. Petr Stehlík, CSc., dr.h.c.

Brno, 20/01/2019