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Abstract

Novel three-step procedure and software tools TransGen and HEN SYN have been developed for Heat Integration and Total Site optimization. The procedure is used for improving Heat Integration within individual plants as well as Total Sites, under fixed or steady-state conditions and under varying or dynamic operational conditions. TransGen is used during the first, targeting step and second, pre-screening step, and HEN SYN for the final synthesis of retrofitted heat exchanger network (HEN). The targeting step is based on a combined Mathematical Programming/ Pinch Analysis approach, whilst the pre-screening and the synthesis step on Mathematical Programming approach. Software tool TransGen is therefore used during the targeting step for analysing potentials for external utilities reduction and production of intermediate utilities in individual plants and Total Sites under uncertainty, and especially it is intended for the pre-screening step for automatic identification of retrofit modifications in existing plants and Total Sites. The tool HEN SYN is finally used to obtain retrofitted HEN designs only for the identified modifications rather than for the whole HEN, which enables one to perform the retrofit of very large-scale problems. The main objective of both tools TransGen and HEN SYN is maximization of economic performance (annual incremental profit) of plants and/or Total Sites by minimization of energy consumption and cost, and maximization of economically-viable production of energy, such as production of hot water for district heating. Both tools consider the trade-offs between operating and investment cost, where HEN SYN considers it in more details. Both software tools are written in data-independent way so that the procedure could be used for any other application just by changing the data. The procedure could be used for handling problems of any size, ranging from small processes up to complex industrial Total Sites. Illustrative example shows the capabilities of the developed software tools and the procedure.

Increased global competition and environmental awareness have forced industrial companies to improve the performances of their processes and also Total Sites and Locally Integrated Energy Sectors, Heat Integration, Total Site Integration and waste heat utilisation within industrial processes and Total Sites is an efficient way of conserving energy and achieving emission reductions. Several approaches have been developed for this purpose. In general they are divided into an approach based on physical insights – Pinch Analysis, and an approach based on numerical mathematics – Mathematical Programming. All the methodologies have their own advantages and drawbacks. In order to optimize the energy consumption within large-scale process plants and Total Sites under dynamic operating conditions the methodologies should be combined and further extended. Over recent years combined Mathematical Programming/ Pinch Analysis approaches for overcoming the drawbacks of both approaches have also been developed.

Novel three-step procedure and software tools called TransGen and HEN SYN have been developed for Heat and Total Site optimization of energy and cost in order to be applied for energy targeting and retrofitting of existing industrial plants and Total Sites. Software tool TransGen is intended for targeting in the first step and for pre-screening of the most optimal retrofitting solutions in the second step. It could be applied under steady-state and under dynamic conditions and for any number of heat exchange units, especially for the plants and Total Site with large number of heat exchange units. The targeting step is based on a combined Mathematical Programming/Pinch Analysis. The pre-screening step is based on Mathematical Programming and on the superstructure mixed-integer linear programming approach. Pre-screening step also narrows the original search space and guides the optimisation towards obtaining (near) global as well as feasible solutions regarding retrofitting. Using TransGen tool it is possible to propose certain number of modifications (new heat exchange matches) that are (or could be) feasible in terms of economical, technological, safety and other limitations. TransGen also enables investigations regarding the trade-offs between the investment and operating costs by accounting for HEN design at plant and Total Site level, pipeline layout, heat and pressure losses, insulation, etc.

Further, at the third-step, software tool HEN SYN is used for more detailed investigation of the trade-offs between investment and operating cost on the reduced space of alternatives. Only those data related to selected modifications at the second step are used in the third step for the synthesis of retrofitted HEN. Third step also enables to easily obtain the final structure

of the retrofitted HEN including positions and temperatures of heat exchangers within the network.

The three-step procedure and the methodology for the Total Site integration within existing Total Sites will be presented in the following and demonstrated on an illustrative example of a Total Site consisting of two process plants.

HEAT AND TOTAL SITE INTEGRATION USING TRANSGEN AND HEN SYN

In order to perform the retrofit of the HENs within large-scale industrial process plants and Total Sites, the combined Mathematical Programming/Pinch Analysis approach has been applied. The following three-step procedure has been developed:

1.) Targeting step based on Mathematical Programming/ Pinch Analysis. By comparing the solutions obtained for target and existing designs, the potential for Heat and Total Site integration and waste heat utilization is identified. Targeting step is performed using software tool TransGen;

2.) Pre-screening step with identification of modifications and forbidding unfeasible matches based on Mathematical Programming, on extension of expanded transhipment model. This step enables obtaining the most optimal retrofitting modifications regarding energy consumption reduction and intermediate utilities production in regards to trade-offs between operating and investment costs. It should be noted also that second step contains several loops in order that the obtained results are (near) optimal, verified and feasible. Second step is also performed using TransGen;

3.) Synthesis step based on Mathematical Programming on the stage-wise superstructure extended for retrofit, different exchanger types and dynamics of operations. It enables obtaining detailed HEN retrofit from those modifications identified during the second step. Third step is performed using software tool HEN SYN.

The following methodology is used for Heat Integration and Total Site Optimisation using the novel three-step procedure and softwares TransGen and HEN SYN:

1.) Data acquisition and incorporation of data in TransGen;

2.) Targeting using software tool TransGen and the comparison with the existing design and energy consumption;
3.) Pre-screening of alternatives for modifications and selection of modifications by forbidding the infeasible matches. Pre-screening and selection of modifications is performed using software tool TransGen;
4.) Verifications of the obtained solutions from step 3 and returning to step 3 as long as all proposed heat exchange matches are acceptable for the leaders and engineers of the plant and/or Total Site. Several loops could be required to obtain (near) optimal, verified and feasible results;
5.) Preparation of the data for selected modifications and the synthesis of the retrofitted HEN using software HEN SYN.

The developed methodology is presented in Figure 1 and demonstrated in Section 3 by illustrative example.

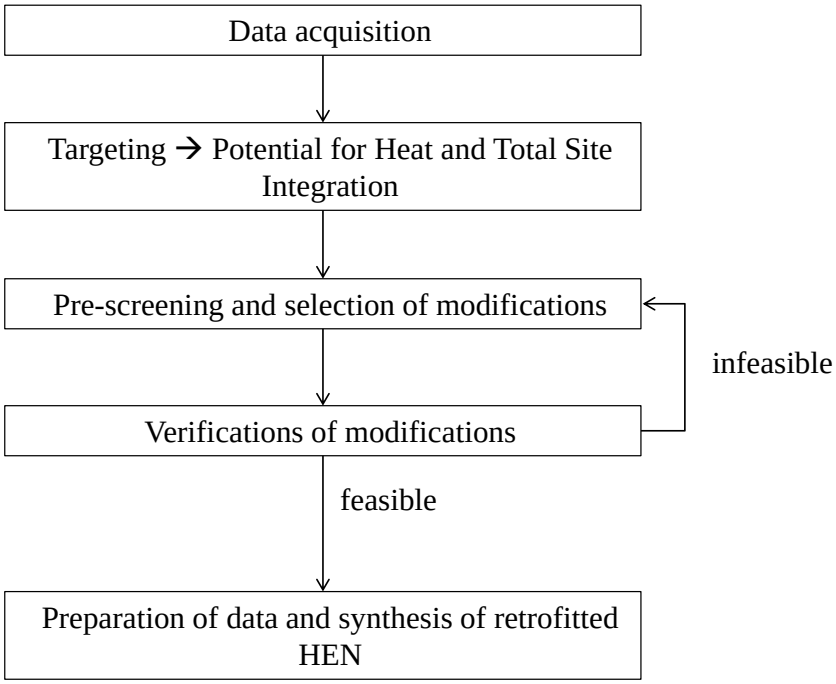

Figure 1 Methodology used for Heat and Total Site Integration

Two tools TransGen and HEN SYN have been developed during the retrofitting of dynamic Total Sites. The tool TransGen enables analysing the large-scale HENs and provides globally-optimal solutions. However from TransGen it is not possible to analyse in details the

obtained modified HENs, and it does not provide the results in the form to be possible to draw HENs. Thus it is combined with the software tool HEN SYN, which enables to obtain such results with minimum effort including positions and temperatures of proposed heat exchangers within the network, and enables also to perform more detailed analysis of the trade-offs between investment and operating cost. However, also HEN SYN could not be used as the only tool for performing Heat and Total Site integration within large-scale industrial processes and Total, especially under varying conditions, because it is non-linear programming-hard and has complex combinatorics and non-convexities involved.

In order for the procedure to be automated, the data regarding the final streams that are included in HEN are automatically generated in TransGen and called into software tool HEN SYN. Both developed tools TransGen and HEN SYN are to be used jointly.

References

[1] Perry S, Klemeš J, Bulatov I. Integrating waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors. Energy. 2008;33(10):1489-97.

[2] Klemeš JJ, Kravanja Z. Forty years of Heat Integration: Pinch Analysis (PA) and Mathematical Programming (MP). Current Opinion in Chemical Engineering. 2013;2(4):461-74.

[3] Nemet A, Klemeš JJ, Kravanja Z. Designing a Total Site for an entire lifetime under fluctuating utility prices. Computers & Chemical Engineering. 2015;72:159-82.

[4] Čuček L, Kravanja Z. Retrofitting of Large-Scale HENs within Total Sites under Uncertainty by considering Trade-Offs between Investment and Operating Costs. Chemical Engineering Transactions. 2015.

[5] Soršak A, Kravanja Z. MINLP retrofit of heat exchanger networks comprising different exchanger types. Computers & Chemical Engineering. 2004;28(1–2):235-51.

[6] Kravanja Z, Čuček L, Process Synthesis: Minimum Utility Cost with Constrained Matches under Uncertainty, Deliverable 9.4: Incorporation of the EFENIS activities/results into Academic Partners' curricula. <efenis.uni-pannon.hu/partners-section/deliverables/>, 2013. Last accessed: 20.1.2015.

[7] Klemeš J, Friedler F, Bulatov I, Varbanov P. Sustainability in the Process Industry: Integration and Optimization: Integration and Optimization. New York, USA: McGraw-Hill Companies, 2010.

[8] Smith RM. Chemical Process: Design and Integration. Chichester, West Sussex, England: John Wiley & Sons, Ltd., 2005.