Pinch Technology Second Generation

Analysis with crisscross optimisation prior to design

Design with loop optimisation for minimum area and minimum cost

EXECUTIVE SUMMARY

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1 Introduction

In 1971, Ed Hohmann stated in his PhD that 'one can compute the least amount of hot and cold utilities required for a process without knowing the heat exchanger network that could accomplish it. One also can estimate the heat exchange area required'.

In the late seventies, Linnhoff and Umeda showed the existence in many processes of a heat integration bottleneck, 'the pinch', which laid the basis for the technique, known today as pinch analysis. Bodo Linnhoff developed the 'Problem Table', an algorithm for calculating the energy targets and worked out the basis for a calculation of the surface area required, known as 'the spaghetti network'. These algorithms enabled practical application of the technique.

For more than 30 years, pinch analysis has been successfully applied in a wide range of industries. Pinch analysis is the only practical tool for defining the minimum energy requirement of a process and for assessing the energy efficiency of existing plants. For new processes, it is used to give a good indication of utility cost and required investment in heat exchanger apparatus and it is specifically useful in exploring process alternatives that might be more efficient in terms of energy consumption. In case of retrofit, the appropriateness of the heat exchanger network can be assessed and the network can be cured if so required. The main advantage of such evaluation is that it can be made without any costly detailed engineering regarding the required heat exchanger network to achieve the envisaged energy consumption targets.

2 Classic Pinch Analysis and assessment of available tools

Classic pinch analysis and available software tools today are based on the Problem Table algorithm. The driver for analysis and trade-off between energy and capital is the minimum approach temperature 'DTMin'. The basis for the surface area calculation is the 'Spaghetti network', assuming vertical heat transfer in the integration diagram.

Notwithstanding successful application of the method, the procedures applied still show serious weaknesses.

It is well known that if heat transfer coefficients of the process streams are not the same, then minimum approach temperatures should not be the same either and DTMin contributions should rather be differentiated according to the stream specific heat transfer coefficients. Attempts to differentiate, however, have failed so far. Further, crisscross heat exchange in the integration diagram might reduce the area required by up to 15%. Since trade-off between energy and capital requires calculation of the area, the value of such trade-off depends upon the accuracy of the area calculation. But no algorithms are known that are able to calculate the minimum area required including the effect of crisscross and, consequently, the result of trade-off analysis is not necessarily reliable.

Data generated by the analysis for initiating the heat exchanger network configuration are based on the assumption of vertical heat exchange. In many cases, developed Heat Exchanger Networks (HEN's) cannot be turned into optimum HEN's by evolution because of topology traps. In case of retrofits, 'pinch violations' are calculated without considering stream specific heat transfer coefficients that might impose crisscross and proposed remedies are not always optimal.

In the meantime many research centres have experimented with procedures involving Mixed Integer Non-Linear Programming and several other even more sophisticated techniques such as Particle Swarm Optimisation or Mono and Hybrid Genetic Algorithms. So far, however, these efforts have not produced reliable and satisfactory results. Admittedly, this is also caused by the fact that the initial data set from classic pinch analysis leads to topology traps from which only sub-optimal solutions can be developed by evolution.

3 Pinch Analysis with Crisscross Optimisation prior to Design

The new Pinch Analysis procedure presented here eliminates the weaknesses of existing tools and improves the reliability of the results and the quality of the data from which to start the design.

The new procedure includes crisscross optimisation in the analysis stage prior to design. In the analysis stage appropriate crisscross heat exchange is defined for achieving minimum surface area without recurring to sophisticated programming techniques. Trade-off between energy and capital cost is done on the basis of integration rather than on the basis of DTMin's, whilst capital cost takes into account effects of crisscross heat exchange 'prior to design'. An optimum data set is generated as a Grid Diagram for initialising the configuration of an optimum heat exchanger network.

4 Heat Exchanger Networks revisited

So far, development of heat exchanger network configurations is based either on application of design rules from pinch technology or on programming techniques initially developed for solving transportation problems.

‘Pinch methods suffer from improper trade-off handling, several topology traps, and are time consuming. MINLP methods suffer from severe numerical problems, difficult user interaction and fail to solve large scale problems. Stochastic optimisation methods use non-rigorous algorithms and the quality of the solution depends on the time spent on search.’ (ref.: NTNU).

New algorithms have now been developed for configuring optimum networks. Whilst the procedure includes setting up of 'superstructures' as done in sophisticated frameworks, the initial definition of these superstructures emerges from the data set generated by the analysis. By inspection and interactive optimisation, the superstructures are simplified until a manageable network can be generated.

In a first step, the network is optimised by targeting minimum heat exchanger surface area, simultaneously with minimum number of heat exchanger units. In a second step, the results are further improved by targeting minimum cost. The intermediate results are analysed and the most promising heat exchangers are challenged for removal. Then the final output is used to set up a HEN flow sheet for further simplification and final optimisation.

5 Evaluation of the new procedures

The analysis tool has been extensively tested and has been finalised. Development of the design tool is still ongoing. The algorithms have been tested for medium sized problems (up to 10 hot streams and 10 cold streams plus utilities) and produce exciting results.

Several reference cases from literature have been studied with the new procedures. The results show that topology traps can be avoided, which is a prerequisite for developing optimum networks. But even more interesting is that it was possible to develop networks with lower cost than what has been published in literature so far. The crisscross analysis has also been tested in an industrial retrofit case and enabled to producing economically attractive modifications whilst classic pinch analysis failed.

6 Practical application

The new algorithms have been developed into practical software tools for PC application and have been programmed in Visual Basic for Excel, Microsoft Office, edition 2003.