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THE PLACEMENT OF TWO-STREAM AND MULTI-STREAM HEAT-EXCHANGERS IN AN EXISTING NETWORK THROUGH PATH ANALYSIS

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ABSTRACT

A prescreening and decomposition method is presented to analyse heat exchanger networks for retrofitting. The method, called Path Analysis, selects and analyses fractions from the existing network, either by heuristics or by an algorithm. By comparison of all fractions, the critical parts of the network that should be adapted can be identified. The adaptations can be done independent of the remaining network. Thus Path Analysis enables a considerable reduction of the effort in retrofit design. Meanwhile the simplest network adaptations are favoured.
Path Analysis is applied to several cases. The results for an aromatics case are presented. Using the right software tools, the engineering effort can be reduced considerably, compared with existing methods. Solutions tend to be less complex, while the profitability is sometimes higher than was expected from global analysis. With Path Analysis the retrofit design using new multi-stream heat exchangers proved to be straightforward.

KEYWORDS

Heat Exchanger Networks; Retrofit; Targeting; Compact Multi-Stream Heat Exchangers

INTRODUCTION

The major part of the available heat integration literature addresses methods developed for grassroots designs (Linnhoff, 1993). Although these methods are valuable for retrofit designs, specific methods should be used to properly find and evaluate possible adaptations to the existing equipment. Full retrofit analysis and design methods have been reported by Tjoe (1986), Carlson *et al.* (1993) and Yee and Grossmann (1991). The former two report on heuristic evolutionary methods, the latter on mathematical programming. All methods perform both the retrofit analysis and design on the complete heat exchanger network that exists. Irrespective of the used method the design of even a near optimal network is complex task. This complexity increases rapidly with the size of the retrofit problem. Tjoe (1986) presented retrofit targets to guide the designer towards at least near optimal networks. Carlson *et al.* (1993), however, recognized that these targets are of limited use, as the costs of different new matches may differ substantially. The designer may thus overlook more cost effective retrofit designs.

A possible way to reduce the complexity is some prescreening procedure that not only estimates an economic heat recovery level, like in previous methods, but also identifies the critical parts of the existing network that should best be adapted. The procedure should thus reduce the design problem without the loss of relevant energy saving potential. Daichendt and Grossmann (1994) have published a mathematical procedure to do a similar screening of grassroots cases. Hui and Ahmad (1994) have published a method to handle zones of integrity, that may also be used. In a study (Van Reisen, 1993) on the use of compact multi-stream heat exchangers in retrofit design a new retrofit analysis tool has been developed. This tool, called Path Analysis, generates a series of subproblems from the total retrofit problem that have high economic potentials. It enables a designer to trade of before design energy conservation, area addition and expected complexity of both the design task and the design itself.

PATH ANALYSIS

Concepts

Path Analysis is a simple decomposition and prescreening procedure that evaluates the economic potential of parts of the existing heat exchanger network, called subnetworks, while the remaining part of the network is unchanged. The evaluation of each subnetwork is done by existing retrofit analysis procedures. So, targeting is performed for energy savings and investments in each subnetwork. The targets of each subnetwork can be compared with each other and with the total network. From this comparison the most promising set of subnetworks is selected and a retrofit design is made, using one of the existing procedures.

The subnetworks can be generated either by the designer based on his knowledge of the process or by an algorithm to allow rigorous analysis of all opportunities. Two rules should always be taken into account. First, all subnetworks should be heat-balanced. This means that heat exchangers and the stream sections covered by them should be selected from the existing network rather than streams with a source and target temperature. If this rule is not obeyed the subnetworks may not be adapted independent from the total network. Second, at least one heater and one cooler should be included in each subnetwork. This is a minimal requirement for an opportunity for energy conservation. In more general terms the subnetwork should consist of a 'flexible' heat sink, including one or more heaters, and a 'flexible' heat source, including one or more coolers. To both the sink and the source process-to-process heat exchangers can be added.

Another requirement for energy conservation is a connection between the heat sink and the heat source. Such a connection, called a path (Linnhoff and Hindmarsh, 1983), can be used to reduce the loads on both the sink and the source. In order to do this, energy is transferred from the source to the sink by process-to-process heat exchange. To save energy, area must be added to existing exchangers in an existing path or to new matches, that create new paths. Adding area to existing exchangers is preferred as it has the lowest impact on the existing structure and it is relatively cheap. When subnetworks are build from fractions of existing paths, the number of new matches needed is as small as possible. This guideline can help to identify promising subnetworks from the total network. It enables the evaluation of the expected complexity of the design task and the design result at the same time the savings and investments targets are available.

Procedure

The steps for retrofit design with Path Analysis are presented in Fig. 1. After data extraction, the saving on investment relationship for the total network are calculated. Any of the existing retrofit or eventually grassroots targeting methods can be used. Also the thermodynamic minimum energy input is determined from the energy target at the minimal approach temperature of 0°C. Both the savings on investment relationship and the minimum energy are used as a reference for further analysis.

The first stage of the Path Analysis is the identification of the subnetworks in which energy savings can be established followed by an analysis of these subnetworks similar to the analysis of the total network. In the previous paragraph the two requirements for such subnetworks have been identified. If the problem is sufficiently small or if appropriate software is available, all possible subnetworks from the simplest paths to the total network, can be evaluated. The number of possibilities increases rapidly with the number of streams, the number of existing matches and the number of heaters and coolers.

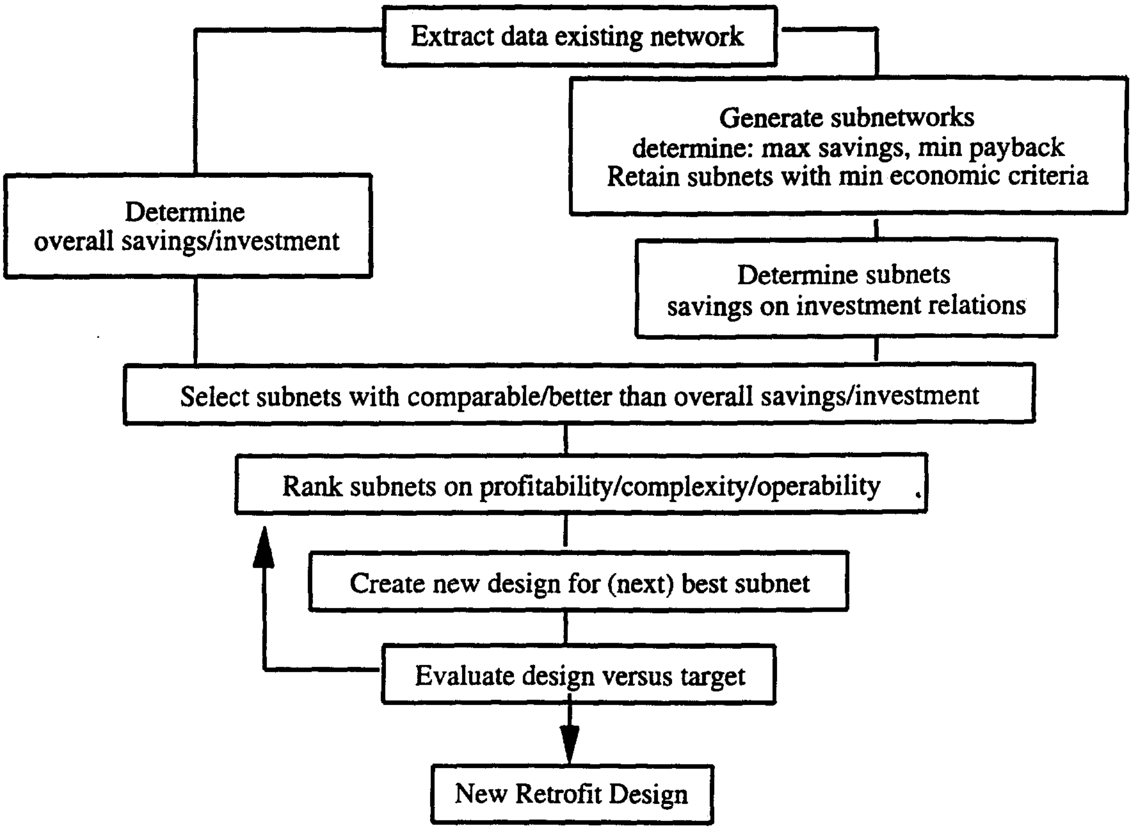

Fig. 1. Schematic representation of the Path Analysis

The second stage is a comparison of all analysed subnetworks. This comparison should not only include the savings and investments, but also the complexity and the practical problems or opportunities of the considered subnetworks. The complexity is primarily determined by the number of streams and the number of exchangers that exist. The size of those exchangers may also be a complicating factor as large areas may be difficult to reuse. Several practical aspects also have influence on the complexity. Streams can be far apart in physical space while others are connected or related according to the flowsheet or plotplans. The subnetworks may differ in the opportunities with respect to physical space and existing civil works to put in new exchangers or in problems related to controllability, flexibility and safety. All these practical aspects greatly influence the total costs of the retrofit project. The currently known cost functions cannot take into account these aspects and thus a somewhat subjective and only qualitative trade off must be done. The Path Analysis shows the energy and area implications of certain choices.

The last stage of the Path Analysis is the creation of a retrofit design for the chosen subnetwork and a comparison of the results with the targets. All streams and matches outside the subnetwork are unmodified. The design phase can thus considerably be simplified. Generally the smaller the project the smaller the chosen subnetwork will be. Thus the engineering effort can be adapted to the proposed scope of the project. The design can be done by one of the methods mentioned in the introduction.

EXAMPLE

The path approach will be illustrated by the aromatics case, discussed by Tjoe (1986). The problem is summarised in Fig. 2. The used cost data is similar: hot utility 0.177 Dfl/W/yr; cold utility 0.02 Dfl/W/yr. The area costs per shell in Dfl were $24 \cdot 10^3 + 1.9 \cdot 10^3$ (shell area)$^{0.83}$. To analyse the network the incremental area efficiency (α) targeting procedure has been used.

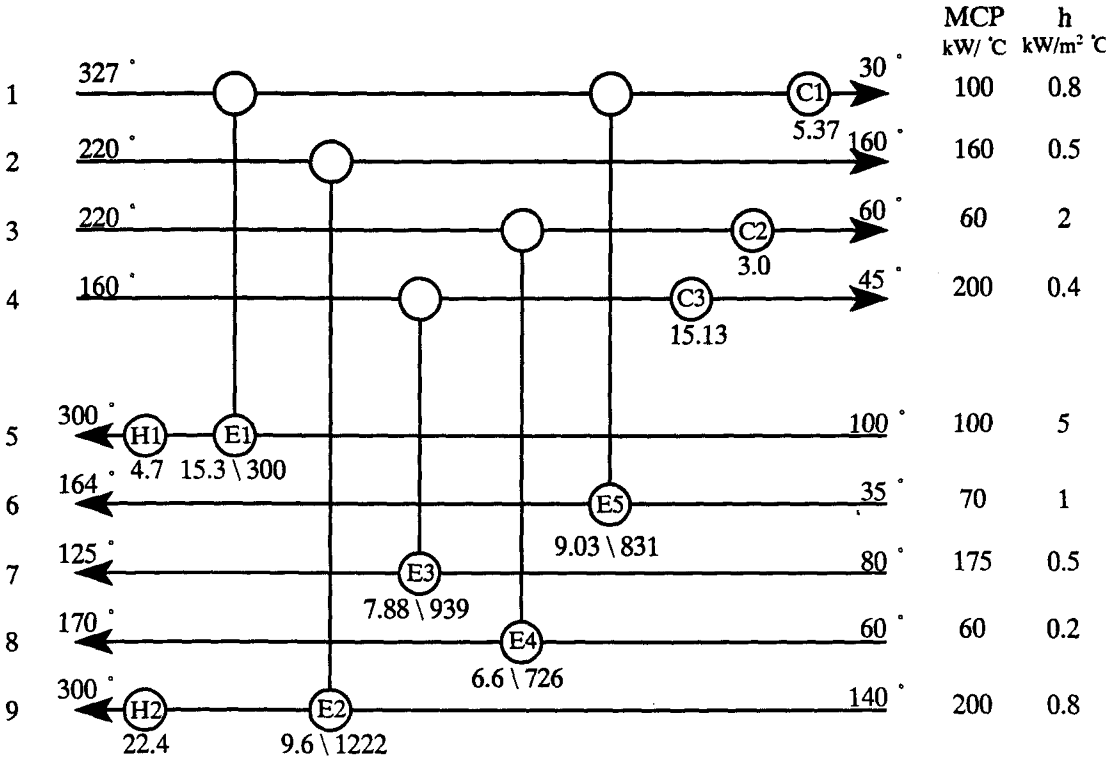

Fig. 2. Data of the aromatics case from Tjoe (1986). Q (kW) \ A (m^2)

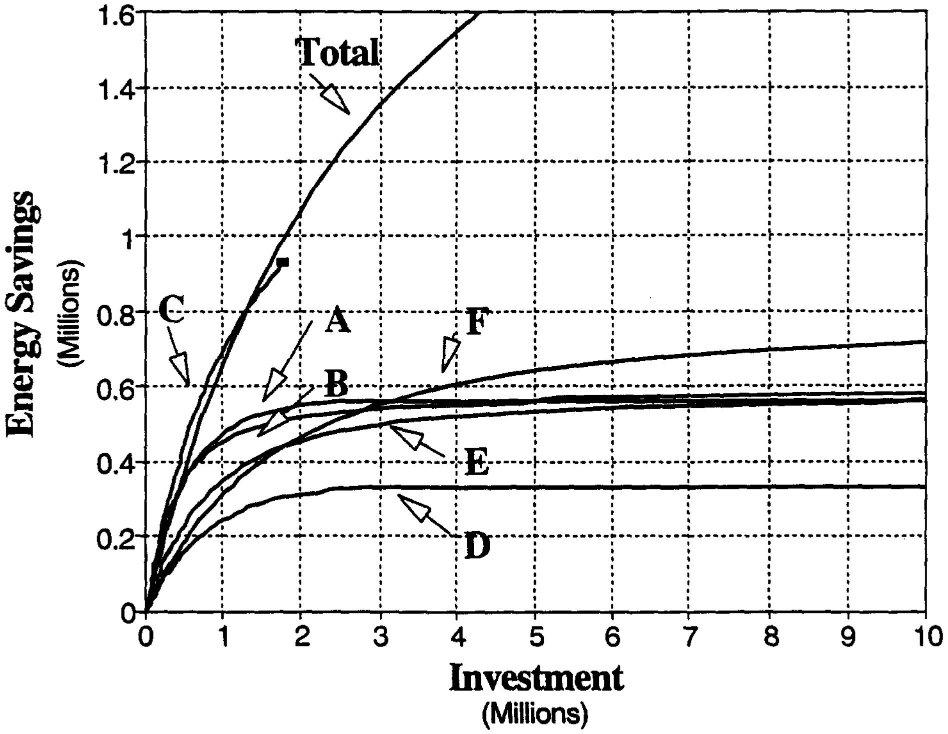

Fig. 3 Savings on investment plots from incremental α targeting of the aromatics case subnetworks: A = H1, E1, E5, C1; B = H1, E1, E4, C2; C = H1, E1, E3, C3; D = H2, E2, E5, C1; E = H2, E2, E4, C2; F = H2, E2, E3, C3;

The existing network contains 4018 m^2 process-to-process exchanger area and uses 27.1 MW hot utility. The area target for the same utility use is 3445 m^2, thus the existing area efficiency is 0.86. The thermodynamic minimum hot utility use is 14.4 MW, allowing a maximum energy saving of 12.7 MW. The targeted savings on investment relationship is plotted in Fig. 3.

The next stage in the Path Analysis is identification of valid subnetworks. Rigorous analysis of the system would require the evaluation of about 220 subnetworks. For illustration purposes only six of them are selected, based on engineering insight in the problem. These subnetworks have been analysed by the same targeting procedure as the total network (Fig. 3).

The savings on investment lines in Fig. 3 clearly show good potential for the retrofit of the total network. Most of the subnetworks have little saving potential compared to the total network and relatively poor rentability as well. The positive exception is subnetwork C, containing the exchangers H1, E1, E3 and C3. It has a substantial saving potential of 4.7 MW and a rentability that is comparable to the total network. Note that complexity is not taken into account in these plots. The curve of C is the only one presented that does not reach infinite investments. This is because there is no process pinch point in this subnetwork. The load on the heater becomes zero at a minimum approach temperature of 14°C. Such situations can be derived directly from the savings on investments plots. If a project is defined with a payback time up to 2 years, subnetwork C will be preferred over the total network because of its rentability and the low complexity. For a payback time abritrarily set to 1.5 years a saving of 3.6 MW can be obtained in the subnetwork, while only 3.1 MW can be obtained in the total network.

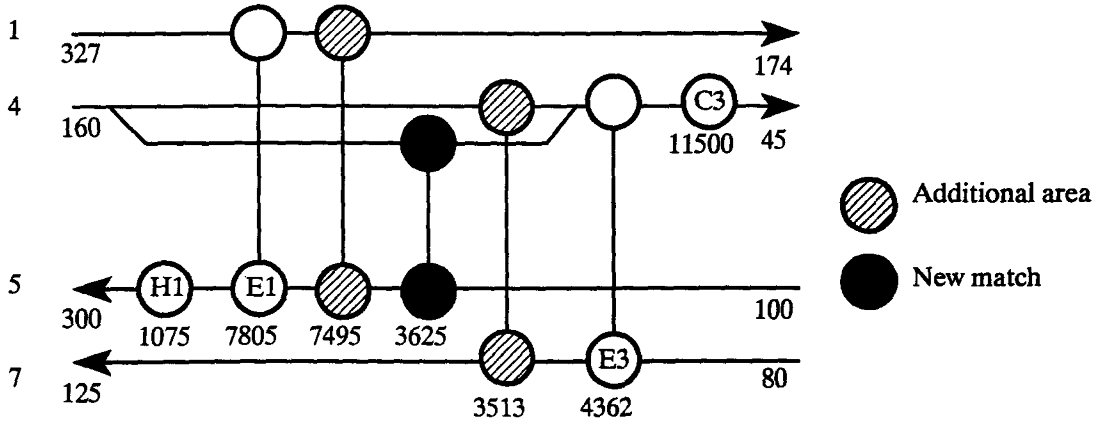

Fig. 4. Final design of the subnetwork with H1, E1, E3 and C3 of the aromatics case

The design of the selected subnetwork C with the exchangers H1, E1, E3 and C3 can easily be done