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Capital and total cost targets for mass exchange networks Part 1: Simple capital cost models

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Abstract

This paper presents a method for targeting the capital and total cost of a mass exchange network. This part of the paper considers stagewise systems and uses a simplified capital cost correlation in order to convey the fundamentals. The method starts by determining the number of stages required, using the $y-x$ composite curve plot presented previously, and then converts this to a capital cost. This target is combined with utility targets to give a target for the total annual cost. Simple design guidelines are presented, which allow these targets to be approached to within a few percent. The method is applied to a coke-oven gas sweetening example, which is a case involving two mass separating agents (MSAs) which do not overlap. It is also applied to an example involving phenol removal, in which there are overlapping MSAs. A final example deals with multicomponent transfer by extending the coke-oven gas problem. The paper introduces a new graphical tool, the $y-y^*$ composite curve plot, for handling systems with overlapping MSAs. The paper demonstrates that, contrary to previous belief, using the minimum number of units does not necessarily lead to a minimum cost design. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Capital cost targets; Pinch analysis; Mass exchange networks

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1. Introduction

Pinch analysis is very well developed for heat exchanger network synthesis (HENS) and has become much more than just an energy-saving tool (Linnhoff, 1993). Specifying the minimum temperature difference, $\Delta T_{\min}$, allows the minimum energy and capital costs to be accurately predicted as targets before design. These costs can be traded off at the targeting stage by varying $\Delta T_{\min}$ in order to minimise the total annual cost (TAC) of the network. This 'supertargeting' (Linnhoff & Ahmad, 1990) locates the optimum value of $\Delta T_{\min}$ without any design being required. Actual designs are then guided so as to achieve the optimised targets. However, the application of pinch analysis to mass exchange network synthesis (MENS) is not as well developed.

El-Halwagi and Manousiouthakis (1989a) introduced the concept of a mass exchange network (MEN). The MENS problem can be stated as:

Given a number of rich streams and a number of lean streams, also known as mass separating agents (MSAs), it is desired to synthesise a cost-effective network of mass exchangers that can preferentially transfer certain species from the rich streams to the MSAs. Given also are the flow rate of each rich stream, G_i, its supply (inlet) composition, y_i^s, and its target (outlet) composition, y_i^t. In addition, the supply and target compositions, x_j^s and x_j^t, are given for each MSA. The mass transfer equilibrium relations are also given for each MSA. The flow rate of each MSA is unknown and is to be determined as part of the synthesis task.

The candidate MSAs (lean streams) can be classified as either process MSAs or external MSAs. The process MSAs already exist on the plant site and can be used for a low cost (often virtually free). The flow rate of each process MSA, L_j, is bounded by its availability in the plant and may not exceed a value of L_j^c. On the other hand, the external MSAs can be purchased from the market and their flow rates are to be determined by economic considerations.

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El-Halwagi and Manousiouthakis (1989a) showed how specifying a minimum composition difference, ε (analogous to $\Delta T_{\min}$ in HENS), locates the mass transfer pinch, which is the thermodynamic bottleneck for mass transfer between process streams. Their work resulted in targets for the minimum MSAs required. They presented two methods to do this. The first is a graphical method which is based on plotting mass transfer composite curves (Fig. 1). Note that in MENS, stream compositions are not equivalent. This contrasts with HENS where stream temperatures are equivalent regardless of which stream is being considered. El-Halwagi and Manousiouthakis (1989a) introduced the concept of corresponding composition scales in order to consider all streams on a common basis. This tool establishes a one-to-one correspondence among the compositions of all streams for which mass transfer is thermodynamically feasible. This correspondence depends on the equilibrium relations and the value of ε. As shown in Fig. 1, each MSA composition, x, is mapped as a corresponding y value and this allows all MSAs to be represented on the same plot. Note that this accounts for driving force considerations since ε values are included in this transformation. Thus, even though the rich and lean curves touch at the pinch, this does not mean there is a zero driving force there. The targets for the minimum MSA requirements are read off this plot as shown in Fig. 1.

The second method developed by El-Halwagi and Manousiouthakis (1989a) is a numerical method called the composition interval method, which is analogous to the problem table of Linnhoff et al. (1982) for HENS.

El-Halwagi and Manousiouthakis (1989) then adapted the pinch design method (Linnhoff & Hindmarsh, 1983) to design MENs which achieve these targets. This method divides the problem into two separate regions, above the pinch (containing all streams or parts of streams richer than the pinch composition) and below the pinch (containing all streams or parts of steams leaner than the pinch composition), and treats each region independently. This 'pinch division' means that no mass transfer should take place across the pinch.

Unlike HENS, there was no way of targeting the capital cost for the network. In design, El-Halwagi and Manousiouthakis (1989a) recommended using the minimum number of units as an attempt to minimise the capital costs. However, this is not always sufficient since the sizes of the exchangers are also important. This is the same type of situation that characterised the early days of pinch analysis (for HENS). Heat exchanger networks could be designed for minimum energy usage, but capital costs were not dealt with as satisfactorily. Designs were steered towards the minimum number of units in an attempt to minimise capital costs (Linnhoff et al., 1982). It was even asserted by Grimes, Rychener and Westerberg (1982) that achieving the minimum number of units would minimise the capital costs. It was only later, when targets for surface area became known (Townsend & Linnhoff, 1984), that capital costs could be dealt with properly (Ahmad, 1985).

El-Halwagi and Manousiouthakis (1989a) also observed that ε is an optimisable parameter for MENs. Increasing ε increases the cost of utilities, but results in lower capital costs. These authors noted that the TAC of a network would pass through a minimum, which corresponds to the optimal value of ε. However, there was no way of knowing the capital costs until the network was designed and so the optimisation could only be done by carrying out many repeated designs. The absence of a capital cost target also meant that

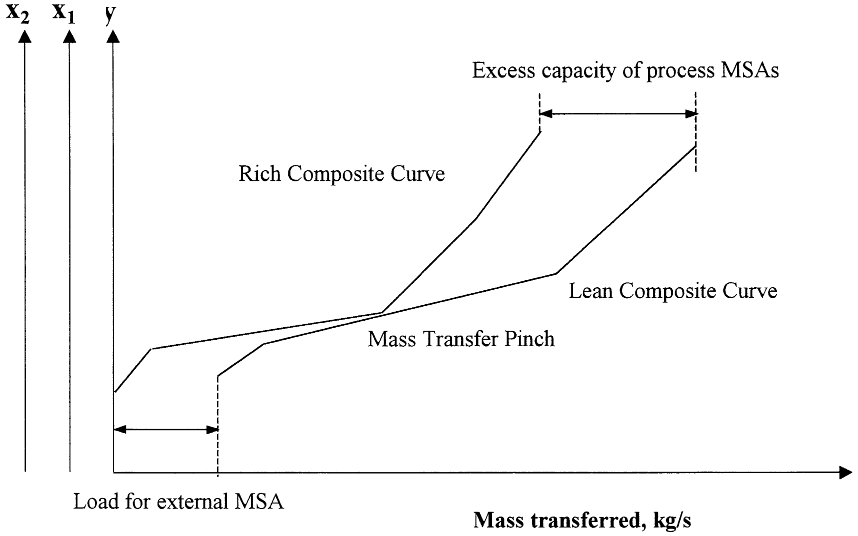

Fig. 1. Mass transfer composite curves.

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