Operation and Design of Diabatic Distillation Processes

Diabatic operation of a distillation column implies that heat is exchanged in one or more stages in the column. The most common way of realising diabatic operation is by internal heat integration resulting in a heat-integrated distillation column (HIDiC). When operating the rectifying section at a higher pressure, a driving force for transferring heat from the rectifying section to the stripping section is achieved. As a result, the condenser and reboiler duties can be significantly reduced. For two-product distillation, the HIDiC is a favourable alternative to the conventional distillation column. Energy savings up to 83% are reported for the HIDiC compared to the CDiC, while the reported economical savings are as high as 40%. However, a simpler heat-integrated distillation column configuration exists, which employs compression in order to obtain a direct heat integration between the top vapour and the reboiler. This configuration is called the mechanical vapour recompression column (MVRC). Energy and economic savings of similar magnitude as the HIDiC are reported for the MVRC. Hence, it is important to develop methods and tools for assisting the selection of the best distillation column configuration. The contributions of this work can be divided in three parts. The first part involves the identification of the preferred distillation column configuration (CDiC, MVRC, or HIDiC) for a given mixture to be separated. Correlations between physical parameters, distillation column design variables, and preliminary feasibility indicators are investigated through simulations studies. The simulation studies include case studies, where different mixtures are separated in different distillation column configurations. The considered mixtures are industrially relevant and their thermodynamic behaviours vary considerable from one another. The HIDiC was found to be the preferred configuration in terms of operating expenditures for mixtures of normal boiling point differences below 10K. The second part involves the investigation of the technological feasibility of the HIDiC. The impact on the column capacity (required tray area, entrainment flooding,weeping) of different column arrangements of the internal heat transfer is investigated. Furthermore, the ability to achieve stable operation of a concentric HIDiC is investigated by systematically designing a regulatory control layer and a supervisory control layer. Stable operation, in terms of column capacity and set point tracking, is demonstrated by simulation. The final part covers the developed simulation tools and methods. A new distillation column model is presented in a generic form such that all the considered distillation column configurations can be described within the same model framework. The following distillation column configurations are considered:

- The conventional distillation column (CDiC)
- The mechanical vapour recompression column (MVRC)
- The heat-integrated distillation column (HIDiC)
- The secondary reflux and vaporisation column (SRVC)

The generic nature of the modelling framework is favourable for benchmarking distillation column configurations. To further facilitate benchmarking of distillation column configurations, a conceptual design algorithm was formulated, which systematically addresses the selection of the design variables. The conceptual design of the heat-integrated distillation column configurations is challenging as a result of the increased number of decision variables compared to the CDiC. Finally, the model is implemented in Matlab and a database of the considered configurations, case studies, pure component properties, and binary interaction parameters is established.

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