Optimization and Experimental Verification of Startup Policies for Distillation Columns

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Keywords: Optimization, Distillation Columns, Start up, Single Columns, Sidestream Columns, Packed Columns, Tray Columns, Energy and Mass Integrated Columns, Reactive Distillation

Startup of distillation columns is one of the most difficult operations of chemical processes. Since it often lasts a period of time, leads to off-products and costs much energy, optimization of startup operating policies for distillation columns is of great interest in process industry. Most previous studies on column startup have been restricted to theoretical investigations such as modeling, simulation and optimization. Due to the complexity of column startup dynamics, it is impossible for a mathematical model to accurately describe the startup operation. Thus the results of theoretical studies on column startup can hardly be applied directly to real plants. In the last few years, we have accomplished both theoretical studies and their experimental verifications with the purpose of developing optimal operating policies for distillation columns. As a result, significant improvement of startup operation can be achieved by implementing the developed startup policies. This paper summarizes our recent results from these studies.

To model a startup operation, we have formulated three different column models. A simple two-stage model was used to estimate the behaviors of startup and to gain a rough insight into the dynamics of distillation columns. Analysis of this model leads to a preliminary result that is an approximation of optimal startup policies (i.e. trajectories of reboiler duty and reflux flow). The second model used was a detailed tray-by-tray model composed of component as well as energy balances, vapor-liquid equilibrium and tray hydraulics. With this model, the startup behavior is described from the first time point at which the equilibrium is reached on the trays. The third model was an hybrid model that depicts column startup from a cold state. Each tray will be described from a nonequilibrium phase in which only mass and energy transfer are taking place to an equilibrium phase in which the vapor-liquid equilibrium is reached. These models have been applied to simulation and optimization of startup for a packed column, a staged column and a heat-integrated column system.

The first case study is a packed column (Fig. 1) with and without sidestream to separate a mixture of esters in vacuum operation. The model was validated through simulation and experimental studies. Heuristics for startup policies of such columns have been developed: total or zero reflux, nominal or maximal reboiler duty and their combinations with an optimal switching strategy. In comparison to the conventional direct setting strategy, the total time of startup is reduced with a factor of six by the developed policy. Furthermore, a dynamic optimization was made based on the validated column model. A sequential dynamic optimization approach for large scale systems was developed, which is based on a transformation of the differential algebraic equations (DAEs) by collocation on finite elements and the SQP algorithm for the optimization step. Implementing the optimized policy
leads to a further reduction of the startup time by a factor of two. In the second case study, the result was applied to a tray column for a three-phase-distillation with a side decanter. The experimental results illustrate a time reduction up to 80% by implementing the optimized startup policy, in comparison to the conventional startup operation.

The third case study is a pilot energy-integrated two-column system (Fig. 2) composed of a high pressure column (HP) and a low pressure column (LP). The pilot plant was so designed that it can be operated in parallel (both columns have top and bottom products), forward (bottom flow of HP is fed to LP) and reverse (bottom outflow of LP is fed to HP) modes. The heat integration leads to a reduction of energy consumption about 50%, but the startup operation of such a column system is more complicated than that of a single column. Dynamic simulation based on the non-equilibrium model has been made and extensive experimental work was done on the pilot plant for startup in different operating modes. Heuristic rules have been developed to minimize the startup time for such processes.

In the paper, the comparison of different applications like single two-product columns versus columns with side-streams, packed columns versus tray columns, energy- and mass-integrated columns in different operating modes and reactive Distillation will be made. The main properties of the different applications and corresponding optimal operating policies as well as the experimental verification will be presented.

Fig.1: A pilot distillation column (packed column)
Rectifying section
Fig. 2: A pilot two-column system with heat integration