Stability Analysis via Poincaré Map for Binary Cyclic Distillation

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Abstract: Cyclic distillation is a periodic process intensification technology in which the upward vapor movement and downward liquid movement are separated in time. This operating principle can reduce liquid back-mixing and may increase the effective separation obtained per equilibrium contact. However, because the process is periodically forced, the appropriate limiting operation is not a time-invariant steady state but a periodic steady state. This work develops a nonlinear-dynamics framework for ideal binary cyclic distillation based on a Poincaré map. A compact continuous-flow binary distillation model is first introduced as a reference model under the same constant molar overflow and constant relative volatility assumptions. Unlike a purely steady-state reference, the continuous-flow model is also written dynamically so that its local stability can be compared with the cycle-to-cycle stability of cyclic operation. The cyclic column is then formulated as a two-period dynamic system consisting of a vapor-flow period and a liquid-flow period. The complete operating cycle defines a Poincaré map from the beginning of one cycle to the beginning of the next. The periodic steady state is a fixed point of this map, and the local stability of the periodic operation is determined by the eigenvalues of the Poincaré map Jacobian. The Jacobian is computed by deriving the analytical state Jacobians of the two period models and integrating variational sensitivity equations along the periodic trajectory. The resulting framework supports stability-aware studies of stage reduction, average boilup reduction, cycle-time selection, relative-volatility effects, and disturbance response.

Keywords: cyclic distillation; process intensification; Poincaré map; periodic steady state; nonlinear stability.