State multiplicity in multi-reaction/reactor-separator-recycle systems

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Abstract

The investigation of the non-linear behaviour of plant with recycles has received a vivid attention during the last years. The study of the generic Reactor-Separator-Recycle systems allows getting valuable insights into the behaviour of complex real plants. Of particular attention is the problem of stability, namely the occurrence of multiple steady states and their assessment. In a previous study we investigated the state multiplicity in Reactor-Separator-Recycle systems involving complex reactions of consecutive and parallel type (Kiss *et al.*, 2003). We demonstrated that multiple steady states are possible and the low branch conversion is typically unstable. The possibility of such behaviour in real plants is very likely. A minimum reactor volume is necessary for feasible operation.

This study deals with nonlinear phenomena, such as state multiplicity and instability, in Reactor-Separator-Recycle (RSR) systems involving multi-reactions, as well as with reactor design and plantwide control issues. One typical scheme is studied, the parallel / consecutive reaction: $A + B \rightarrow P$; $A + P \rightarrow R$, both reactants being recycled. In order to elucidate the state multiplicity problem, this work proposes a dimensionless model that is amenable to analytical or numerical investigation. The results are expressed in terms of dimensionless parameters related to *reactor design* (plant Damköhler number), *separation performance* (product and recycle purity) and *reaction kinetics*.

If the control structure implies self-regulation of the mass balance for one or more reactants, multiple steady states are possible, the low-conversion one being unstable. Control structures involving self-regulation are feasible only if there are sufficient reactions to adjust the consumption rate of each reactant such that no accumulation occurs. All feed flow rates can be set on flow control only if the rank of the stoichiometric matrix is higher than or equal to the number of reactants. Design guidelines that enlarge the feasibility region and avoid unstable states or regions where no steady states exist are recommended. These guidelines should be considered during the conceptual stage of recycle systems design. An industrial case study confirms the theoretical analysis.

Keywords: state multiplicity, nonlinear behaviour, multi reaction / reactor, recycle systems, integration of design and control

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