Inherently Safer Design Oriented Segregation of Chemical Process Operating Region

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Abstract

As known, to keep chemical process running stable is the prerequisite for the safe production. It has been recognized that the stability and controllability are two important inherent characteristics of a process in terms of its operability. Many chemical systems exhibit input/output multiplicity characteristics and non-minimum phase behavior. These inherent characteristics are known to cause limitations in process operation, so it is useful to have some information about these characteristics at the early design stage of a chemical process. Focusing on inherently safer designs, this paper addresses a strategy for classifying the process operating region into distinct zones at the early stage of process design, based on stability/instability and minimum/non-minimum phase behavior analysis. The detailed steps are as follows.

1. Set up dynamic mathematical modeling of the chemical process described by differential algebraic equations (DAEs).
2. Solve the DAE, based on the extended homotopy continuation algorithm, to obtain all the steady states.
3. Obtain the zero dynamics of the chemical process.
4. Determine the characteristics of the steady states (stable or unstable), based on singularity theory and bifurcation theory.
5. Solve eigenvalues of the Jacobian of zero dynamics to determine whether the zero dynamics are stable or unstable.
6. Segregate the whole operating range into distinct zones, based on the results obtained from steps 4 and 5.

The strategy is applied to a process flow-sheet composed of two well-mixed, non-isothermal continuous stirred-tank reactors (CSTRs) with interconnections, where three parallel irreversible elementary exothermic reactions occur. The feasibility region of the process is classified into zones with different characteristics. The results provide information that is very important for guiding process design and operation about how the inherent properties of a process change with changes in its operating conditions, based on which the problem of selecting the normal design/operation parameters could be tackled appropriately.

From this study, conclusions can be drawn:

1. For a process, the steady state solutions change when the feed flow rate and recycle flow rate vary, at the same time system’s stability and phase behavior change. The same situation can take place with other parameters in the process system.
2. Because the system’s contained equipment or subsystem differ from the global system in terms of these features, system’s stability and phase behavior should be considered totally.
3. If the maximum conversion point in a process is unstable and with non-minimum phase behavior, controller designs are more difficult and challenging. Consequently, it is important to account for the trade-offs between stability, controllability and profitability or product quality when selecting a set of normal design/operating parameters.

Keywords: Process System, Inherently Safer Design, Stability, Phase Behavior, Zone Classification,