Abstract

Studies on Globally Linearizing Control with Nonlinear State Estimation for Distillation Columns

By

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Distillation columns are the extensively used separation process in chemical and petroleum industry. This fractionating column shows high dimensional coupling with severe nonlinearity and are subject to a complex interactive set of operational constraints. As a result, high quality control of this unit is a challenging endeavor. This dissertation presents a study on nonlinear estimation and control for distillation columns. To investigate the promising performance of the proposed estimation and control methods, several simulation experiments have been carried out on the binary as well as the multicomponent distillation systems.

Various open-loop observation schemes, namely open-loop estimator (OLE) and reduced-order open-loop estimator (ROOLE), have been designed for a distillation column using exact process model. The comparative performance study showed the better performance of ROOLE over OLE within the globally linearizing control (GLC) framework. Subsequently, three different chemical processes, a CSTR and two binary distillation columns, have been used to run the simulation experiments and to show the superiority of the GLC-ROOLE control scheme over the conventional PI controller.

The model predictive controller (MPC) has constraint handling ability and the GLC law is computationally less expensive. To acquire the benefits of MPC and GLC, a hybrid control structure, namely GLC-QDMC (globally linearizing controller coupled with quadratic dynamic matrix controller) has been proposed. Two variable constraint mapping optimizers have been developed that transform the input constraints of the nonlinear process into constraints on the manipulated input(s) of the globally linearized system. Open-loop observation schemes were used within the GLC-QDMC structure for state estimations. The comparative performance of constraint mapping algorithms was illustrated by a simulated distillation column.

In presence of uncertainties and unmeasured disturbances, the open-loop observation schemes failed to estimate the states accurately and consequently, the corresponding observer-based controller performance was degraded drastically. Motivated by these facts, a closed-loop extended Kalman filter (EKF) was designed for a multicomponent distillation column. Since, EKF involves excessive computational burden, the EKF design for a five-component distillation system has been performed using an ideal binary distillation column model (light key/heavy key). In addition, the EKF predictor model has been developed considering no energy balance equations, constant relative volatility to represent the vapor-liquid equilibrium and simple tray hydraulics equation. Through the simulation experiments, notable performance has been achieved by the GLC-EKF over the GLC-ROOLE control scheme.

In addition to the huge computational time requirements, the estimation error convergence capability of EKF is questionable. In the present work, an adaptive state estimator (ASE) has been developed for a distillation column to estimate the required states as well as poorly known parameters based on the available measurements. The parameters were considered as extra states with no dynamics and these parameters may not be equal in numbers to the measured states. The design of GLC-ASE was performed for the same alcohol column and the simulation results showed the excellency of the proposed GLC-ASE over the GLC-EKF and conventional PI controllers.

The simulation of a complex debutanizer column is presented and the example process recovered butane from unstabilized naphtha feed of components ranging from C_2 to C_8. Vapor-liquid equilibrium and enthalpies were calculated using the Soave-Redlich-Kwong (SRK) equation of state. The design of ASE has been performed for the debutanizer column. The robust observation scheme simultaneously estimated the states as well as poorly known parameters as per the GLC requirements precisely. The design of GLC-ASE and application to the example multicomponent distillation system also has been carried out. The superior performance of GLC-ASE control algorithm has been achieved over the dual-loop PI controller.