High-purity control of internal thermally coupled distillation columns based on nonlinear wave model

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ABSTRACT

Internal thermally coupled distillation column (ITCDIC) is a frontier of energy saving distillation researches, which is a great improvement on conventional distillation column (CDIC). However its high degree thermal coupling makes the control design a bottleneck problem, where data-driven model leads to obvious mismatch with the real plant in the high-purity control processes, and a first-principle model which is comprised of complex mass balance relations and thermally coupled relations could not be directly used as control model for the bad online computing efficiency. In the present work, wave theory is extended to the control design of ITCDIC with variable molar flow rates, where a general nonlinear wave model of ITCDIC processes based on the profile trial function of the component concentration distribution is proposed firstly; combined with the thermally coupled relations, a novel wave model based generic model controller (WGMC) of ITCDIC processes is developed. The benzene–toluene system for ITCDIC is studied as illustration, where WGMC is compared with another generic model controller based on a data-driven model (TGMC) and an internal model controller (IMC). In the servo control and regulatory control, WGMC exhibits the greatest performances. Detailed research results confirm the efficiency of the proposed wave model and the advantage of the proposed WGMC control strategy.

1. Introduction

Distillation column is a key part in the separation processes. Since it consumes large amount of energy, any improvement of its energy efficiency could produce a significant impact on the economic profit in the industry. ITCDIC is an excellent improvement on conventional distillation columns (CDIC), where reboiler and condenser are no longer needed, and energy recovery is realized by transferring heat from the rectifying section to the stripping section [1–10]. Though the large energy saving potential of ITCDIC has been confirmed by many researchers, high degree of thermal coupling between the rectifying section and the stripping section brings complex influences on the dynamic behaviors in ITCDIC [11–14]. The strong nonlinearity and high sensitivity to operation conditions pose a huge challenge on its control design [15–18]. The tight control of ITCDIC not only desires an elegant control strategy but also requires an efficient control model.

Traditional approximating models have great difficulty in describing the abundant complex nonlinear dynamics of ITCDIC. Linear models are often valid only in a small neighborhood of the nominal operating point [19] and cannot describe the distinct nonlinear behavior of ITCDIC. It hardly works in the high-purity control processes [20–22]. Data-driven models are popular alternatives to linear models, for they are easily obtained with simple constructions. Based on data-driven models, many control designs of ITCDIC have been carried out. Nakaiwa [23] proposed an internal model control (IMC) strategy, compared with multi-loop proportional, integral, and derivative control (M-PID). IMC attains better control performance when set-point transfers. However it is extremely sensitive to changes in the operating conditions, and its regulatory performance drastically deteriorates. M-PID can overcome external disturbances fairly well, but it does not deal effectively with the interactive nature of ITCDIC. Though modified IMC, adaptive predictive M-PID [24,25] make some improvement on the above problems, the performance of the controller still degrade greatly when used for high purity control. The main reason is that severe model mismatch between the formulated model and the real plant occurred when operation conditions change. First-principle model [26] is proved to be a most effective one to capture the rich nonlinear dynamics. It is usually used to analyze the distinct behavior of a complex process. Due to the high degree of thermally coupled relations, the first-principle model of ITCDIC is expressed as a complex structure, which makes it hardly realized as a control model for its bad online computing efficiency.

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