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Unique influences of reboiler inventory control on the operation of totally reboiled reactive distillation columns☆

Kejin Huang [1,*], Yang Yuan [1], Liang Zhang [1], Haisheng Chen [1], Shaofeng Wang [1], Nian Liu [2]

[1] College of Information Science and Technology, Beijing University of Chemical Technology, Beijing 100029, China
[2] Electrical & Instrument Department, Wuhuan Engineering Co., Ltd, Wuhan 430223, China

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ABSTRACT

In this work, the dynamics and operation of the totally reboiled reactive distillation columns are visualized in terms of transfer function based process models. This kind of processes is found to be characterized by under-damped step responses due to the special topological configuration and the intricate interplay between the reaction operation and the separation operation involved. The under-dampness can be substantially alleviated through the tight inventory control of bottom reboiler and this presents beneficial effects to process dynamics and operation. Two totally reboiled reactive distillation columns, separating, respectively, a hypothetical synthesis reaction from reactants A and B to product C, and a real decomposition reaction from 1, 4-butanediol to tetrahydrofuran and water, are employed to demonstrate these uncommon behaviors. The results obtained give full support to the above qualitative interpretation. Despite the strong influences of reaction kinetics and thermodynamic properties of the reacting mixtures, the totally reboiled reactive distillation columns are generally considered to present such unique behaviors and require tight inventory control of bottom reboiler to facilitate their control system development.

1. Introduction

Reactive distillation columns (RDCs), being known as one of the most effective alternatives of process intensification, have received comprehensive attention over the past two decades [1–8]. Although the combination between the reaction operation (RO) and the separation operation (SO) involved serves as the major impetus for reducing capital investment and operating cost as compared with their conventional counterparts, it also bears the blames for the occurrence of complicated process dynamics and degraded controllability issues [9–11]. In spite of the fact that deep insights were already acquired into process design, process dynamics, and process operation, little progress has been made so far on the interpretation of the interactions between process design and process dynamics and operation [12]. Since this represents a key issue encountered in the development of RDCs, it is apparently imperative to gain a thorough understanding into the mechanism. In the current article, the totally reboiled reactive distillation columns (TRRDCs) are chosen to be investigated because they stand for one of the simplest combinations between the RO and the SO involved.

The cardinal purpose of this article is to investigate the dynamics and operation of the TRRDCs with special attention paid to their dependence on the special topological configuration. The interaction between the RO and the SO involved is analyzed in terms of transfer function based process models and found to be the primary reason for the occurrence of under-damped step responses. With the tight inventory control of the bottom reboiler, the under-dampness can be substantially eliminated and this yields a beneficial effect to process dynamics and controllability. In terms of two RDCs, separating, respectively, a hypothetical synthesis reaction from reactants A and B to product C and a real decomposition reaction from 1, 4-butanediol (BDO) to tetrahydrofuran (THF) and water, the unique behaviors of the TRRDCs are highlighted. Both open-loop tests and closed-loop control studies are carried out and the outcomes obtained are in good accordance with the insights acquired from the transfer function model based analysis.

2. Dynamics *versus* Reboiler Inventory Control of the TRRDCs

When a RDC has been developed to operate in a totally reboiled operation mode, for example, in the separation of a reversible synthesis

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* Corresponding author.
E-mail address: huangkj@mail.buct.edu.cn (K.J. Huang).

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reaction A + B ↔ 2C ($\alpha_C > \alpha_B > \alpha_A$) as shown in Fig. 1a, the lightest product C is extracted from the top and no discharge is from the bottom. Stripping section is thus not needed and the reactive section is directly connected to the bottom reboiler, thus exhibiting a simpler structure than those RDCs with double outlets at the top and bottom, respectively. While the reactive section serves as an equivalent reactor for the RO involved, the rectifying section is in charge of the SO involved, both receiving energy supply from the bottom reboiler.

Since the quality of top product is the main controlled variable and reflux flow rate is usually the corresponding manipulated variable, it

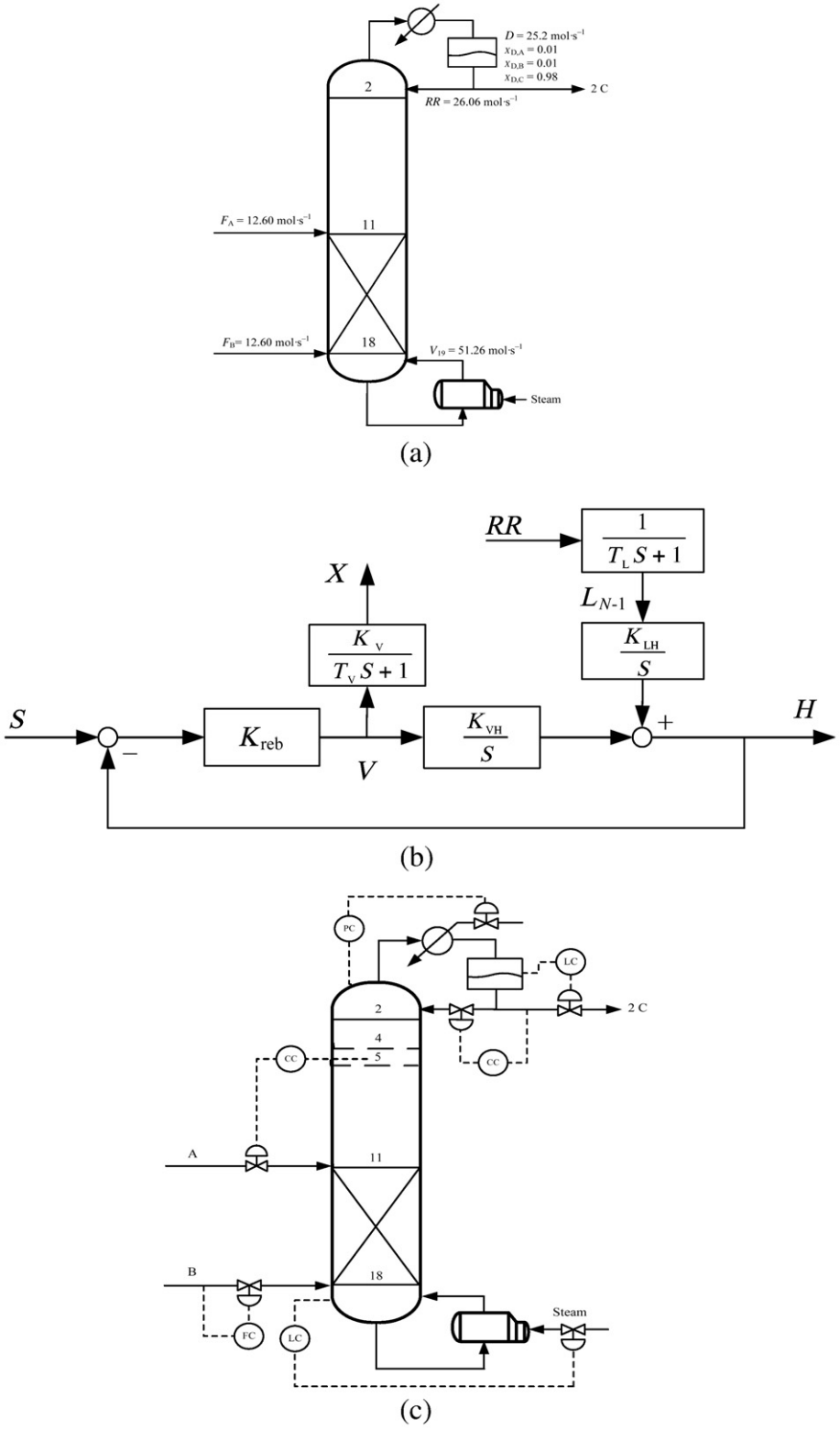

Fig. 1. A totally reboiled reactive distillation column separating a hypothetical synthesis reaction A + B ↔ 2 C (Example I). (a) Scheme, (b) block diagram of the reboiler inventory control loop, (c) control structure.