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Process control analysis for intensified bioethanol separation systems

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ABSTRACT

The purification of bioethanol is traditionally performed by extractive distillation using three column sequences. In the present work new arrangements composed of two columns are considered for the analysis of control properties. The control properties study was based on the controllability properties under open loop operation, followed by the dynamic behavior for common industrial operating disturbances. Simulation results were analyzed by the singular value decomposition technique. The results from the theoretical control properties indicate that the presence of a side stream in the extractive distillation sequences does not necessarily provide operational disadvantages. The results also suggest that control properties are ruled by the kind of solvent used. The best performances were obtained when glycerol is used as entrainer.

1. Introduction

Energy efficient distillation sequences for bioethanol purification are nowadays more essential than ever to speed up the use of bio-derived fuels. The importance on defining the optimal sequence for a multicomponent separation has been discussed for many years and still now represents a very important topic. Three important steps can be identified during the design procedure: the definition of a methodology to generate the alternative sequences, the definition of which type of configurations should be included in the searching space (simple columns or/and complex columns) and the control properties analysis of the selected alternatives.

The evaluation of the energy consumption and of the capital costs is usually performed by steady-state simulations in order to identify the most promising configurations among all the alternatives. Anyway, only analyzing the dynamic behavior of the selected alternatives it is possible to define their applicability. The process control analysis completes the synthesis alternatives generation and in many cases is essential to highlight some design drawbacks. If fully thermally coupled sequences are considered, these configurations were introduced by Petlyuk [1]. The presence of two vapor transfer streams from the same column, limited their applicability even if the steady-state analysis proved a consistent energy reduction compare to the classical simple column design [2–5]. This aspect catalyzed the study of new designs which were able to overcome the problem of vapor transfer from one column to another [6,7].

A similar case is reported for the so called Dividing Wall Column (DWC) patented 70 years ago [8], and recently reconsidered as a valid alternative to decrease the energy consumption of separations by distillation. The barrier that delayed its commercial implementation was mainly the lack of knowledge in modeling and control. These barriers are today overcome [9,10] and different DWCs are installed.

The present study considers a set of alternatives recently proposed [11,12]. In those papers the alternatives were evaluated only for their steady state performance.

The subspace of sequences selected as best options for the bioethanol production, are here reconsidered for the analysis of their dynamic performance. The study of the control properties represents the last step in the selection of the most promising configuration.

2. Sequences analyzed

This section introduces the configurations considered for the dynamic analysis. Five sequences have been selected considering their low energy requirements and the total annual cost. The first sequence (CLR), as reported in Fig. 1a, consists on a

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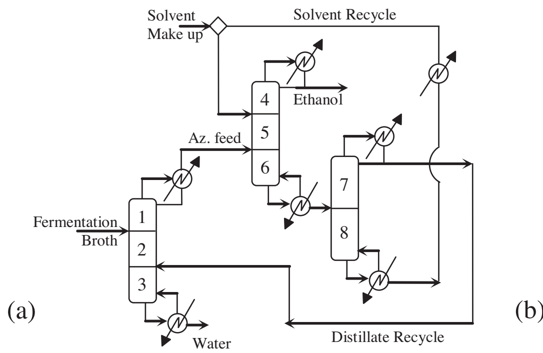

Fig. 1. Conventional separation sequences: (a) CLR with liquid recycle and (b) CVR with vapor recycle.

prefractionator, in which water–ethanol mixture is partially separated until a purity close to the azeotrope is reached, followed by an extractive distillation column where, using an entrainer, pure ethanol is obtained at the top section of the column. Finally, the solvent is recovered in the last column of the sequence. In the top section of the solvent recovery column a water–ethanol liquid mixture is obtained, which is recycled to the prefractionator. The second configuration (CVR) has the same lay out of the previous one, but the water–ethanol mixture at the top of the solvent recovery column as a vapor using a partial condenser and is depicted in Fig. 1b. Configurations CLR and CVR can be classified as conventional separation sequences. The third configuration analyzed (SSVR), reported in Fig. 2, belongs to the category of intensified sequences and consists of two columns. The prefractionator, followed by the extractive distillation column with a side stream. In the extractive column, bioethanol is obtained at the top, the solvent is recovered at the bottom and the vapor side stream that contains a mixture of water and ethanol, is recycled to the prefractionator. The fourth sequence (TCLR) consists of a DWC, modeled considering its equivalent thermally coupled configuration [12]. As reported in Fig. 3a, a liquid stream containing water and ethanol, is recycled to the prefractionator. Ethanol is obtained as distillate of the main column, while the solvent is recovered at the bottom. The fifth sequence (TCVR) is similar to the previous one, but the recycled mixture ethanol–water is obtained in vapor phase (Fig. 3b).

Thus, the subspace of configurations under analysis includes conventional sequences, two-column sequences with a side stream and sequences with thermal couplings. Furthermore, the influence of the entrainer type is also studied.

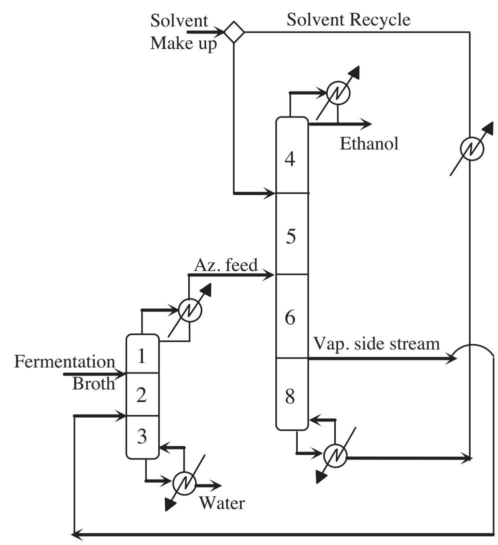

Fig. 2. Two-column sequence (SSVR) with vapor side stream.

3. Steady state analysis

A diluted ethanol–water solution hypothetically produced from a fermentation process is considered as a feed for all the cases

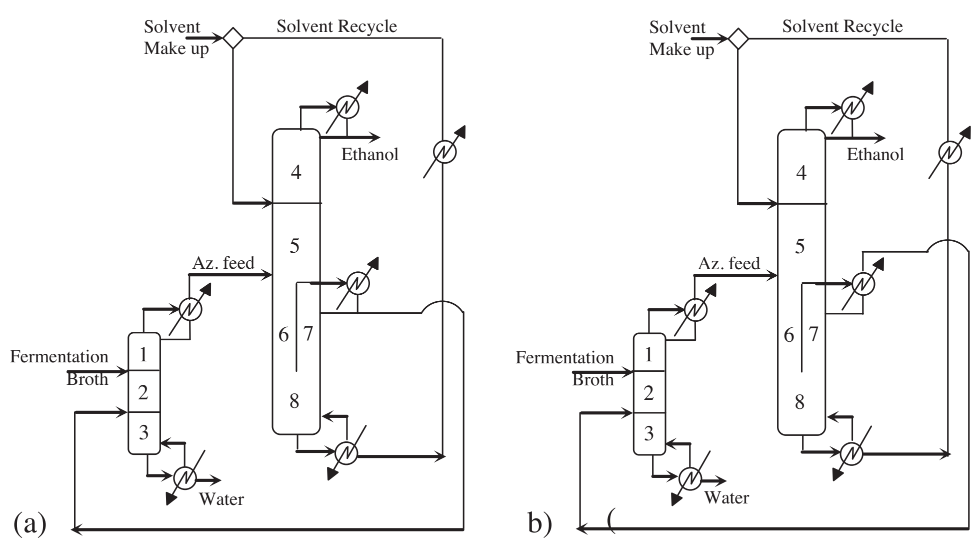

Fig. 3. DWC/thermally coupled sequence: (a) TCLR with liquid recycle and (b) TCVR with vapor recycle.