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Conceptual process design of extractive distillation processes for ethylbenzene/styrene separation

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ABSTRACT

In the current styrene production process the distillation of the close-boiling ethylbenzene/styrene mixture to obtain an ethylbenzene impurity level of 100 ppm in styrene accounts for 75–80% of the energy requirements. The future target is to reach a level of 1–10 ppm, which will increase the energy requirements for the distillation even further. Extractive distillation is a well-known technology to separate close-boiling mixtures up to high purities. The objective of this study was to investigate whether extractive distillation using ionic liquids (ILs) is a promising alternative to obtain high purity styrene. Three ILs were studied: [3-mebupy][$B(CN)_4$], [4-mebupy][BF_4], and [EMIM][SCN]. Extractive distillation with sulfolane and the current conventional distillation process were used as benchmark processes. The IL [4-mebupy][BF_4] is expected to outperform the other two ILs with up to 11.5% lower energy requirements. The operational expenditures of the [4-mebupy][BF_4] process are found to be 43.2% lower than the current distillation process and 5% lower than extractive distillation with sulfolane extractive distillations. However, the capital expenditures for the sulfolane process will be about 23% lower than those for the [4-mebupy][BF_4] process. Finally, the conclusion can be drawn from the total annual costs that all studied extractive distillation processes outperform the current distillation process to obtain high purity styrene, but that the ILs evaluated will not perform better than sulfolane.

Keywords: Sulfolane; Ionic liquids; Extractive distillation; Ethylbenzene; Styrene; Conceptual design

1. Introduction

A typical 500,000 metric tonnes annually (mta) styrene production plant (Welch, 2001) contains an ethylbenzene/styrene distillation column with about 70 equilibrium stages, which operates at a reflux ratio of 7.1 to achieve an ethylbenzene impurity level in the final styrene product of 100 ppm (Chen, 2000). This column accounts for 75–80% of the total energy requirements in the current production process (Welch, 2001). The future target is to reach ethylbenzene impurity levels of 1–10 ppm. It is anticipated that the energy (and capital) requirements will increase even further if distillation is applied to obtain these higher purities. Obviously, an alternative technology is desired, which should replace the current distillation. A promising alternative is extractive distillation, which is a well-known technology to decrease the operational and capital expenditures (OPEX and CAPEX) for the separation of close-boiling mixtures (Lee and Gentry, 1997; Gentry et al., 2004; Lei et al., 2005; Souders, 1964). Extractive distillation is already applied to produce high purity aromatics (Gentry et al., 2004). The commonly applied solvent sulfolane (Lei et al., 2005; Steltenpohl et al., 2005) is a promising organic solvent, which can increase the relative volatility of the ethylbenzene/styrene mixture up to 2.3 (Gentry et al., 2004; Jongmans et al., 2011a). Nevertheless, sulfolane has a significant vapor pressure and, therefore, can contaminate the final (high purity) styrene product. Ionic liquids (ILs) are often reported as promising alternatives for commonly applied organic solvents (Marsh et al., 2004; Meindersma et al., 2007; Giernoth, 2010; Beste et al., 2005), due to their negligible vapor pressure (Beste et al., 2005;

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