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Pressure swing batch distillation by double column systems in closed mode

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ABSTRACT

Two new double column systems operated in closed mode are suggested for pressure swing batch distillation. These configurations are investigated by feasibility studies based on several simplifying assumptions (e.g., infinite plate number, no stage hold-up) and are compared with double column batch rectifier and double column batch stripper in open mode. We study the configurations also by rigorous simulation based on less simplifying assumptions using a professional dynamic simulator. For the different configurations the influence of the most important operational parameters is studied. The results obtained for open and close modes are compared. The calculations and the simulations are performed for a binary minimum (acetone–n-pentane) and for a maximum (ethylene-diamine–water) azeotrope mixture.

1. Introduction

Distillation is the separation method most frequently applied in the chemical industry. For the separation of azeotropic mixtures a special distillation method must be applied such as the *pressure swing distillation* (PSD), extractive or heteroazeotropic distillation. The pressure swing distillation is the least studied from these three methods.

Batch distillation (BD) has always been an important part of seasonal, uncertain or low capacity and high-purity chemicals' production (Mujtaba, 2004; Stichlmair & Fair, 1998). It is a process of key importance in the pharmaceutical and several other industries and in the regeneration of waste solvent mixtures.

The batchwise realisation of the special distillation methods with the application of a separating agent received great attention during the last decade. The *homogeneous batch extractive distillation* with the use of a heavy solvent in a rectifier was investigated among others by Lang, Yatim, Moszkowicz, and Otterbein (1994), Duessel and Stichlmair (1995), Lelkes, Lang, Benadda, and Moszkowicz (1998), Lang, Kovacs, Kotai, Gaal-Szilagyi, and Modla (2006), Kotai, Lang, and Modla (2007) and in a non-conventional configuration (mainly in middle vessel column) among others by Safrit, Westerberg, Diwekar, and Wahnschafft (1995), Warter and Stichmair (1999), Cui, Yang, and Zhai (2002), Low and Sorensen (2002), Warter, Demicoli, and Stichmair (2004), Steger et al. (2006), Hua, Li, Xu, and Bai (2007).

The different aspects of the *heterogeneous batch distillation* were studied among others by Modla, Lang, and Molnar (2001), Modla, Lang, Kotai, and Molnar (2003), Rodriguez-Donis, Gerbaud, and Joulia (2002), Rodríguez-Donis, Acosta-Esquijarosa, Gerbaud, Pardillo-Fondevila, and Joulia (2005), Chien, Zeng, Chao, and Liu (2004), Skouras, Kiva, and Skogestad (2005), Skouras, Skogestad, and Kiva (2005), Xu and Wand (2006), Pommier et al. (2008). A general method for the calculation of residue curves and for the determination of batch distillation regions of heteroazeotropic distillation was suggested by Lang and Modla (2006). Lang et al. (2008) suggested a new double column system operated in closed mode for heterogeneous batch distillation. On the basis of the results of feasibility studies and rigorous simulation (Denes et al., 2008) they stated that the new configuration proved to be feasible and competitive with the conventional batch rectifier. For a binary mixture double column system gave similar and for a ternary one better performance than the batch rectifier (Denes, Lang, Modla, & Joulia, 2009). Its main benefit is that it produces less by products to be separated later Skouras and Skogestad (2004a,b).

Many mixtures form an azeotrope, whose position can be shifted substantially by changing system pressure, that is, a *pressure sensitive azeotrope*. (At some pressure the azeotrope may even disappear.) This effect can be exploited to separate azeotropic mixtures without the application of a separating agent by the so-called *pressure swing distillation*.

Lewis (1928) was the first, who suggested distilling the azeotropic mixtures by pressure swing distillation (PSD). This process has been suggested to separate azeotropic mixtures by, e.g., Black (1980), Abu-Eishah and Luyben (1985), Chang and Shih (1989). More details about the pressure swing continuous distil-

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Nomenclature

BP	bubble point (°C)
D	distillate molar flow rate (kmol/s)
L	liquid molar flow rate (kmol/s)
N	plate number
P	pressure (bar)
R	reflux ratio
R_s	reboil ratio
SD	amount of distillate (kmol)
SPr	amount of the product (kmol)
SQ^{total}	overall energy consumption (MJ)
T	temperature (°C)
t	time (h)
U	liquid hold-up (kmol)
V	vapour molar flow rate (kmol/h)
W	bottom molar flow rate (kmol/h)
x	liquid mole fraction
y	vapour mole fraction

Greek letters

ϕ	division
τ	duration of the step (h)

Subscripts

A	component A
AZ	azeotrope
b	beginning of the step
B	component B
ch	charge
D	distillate
e	end of the step
f	feed
i, j	components
Q	heat duty
$spec$	specified value
L	liquid
LV	liquid leaving of vessel
V	vapour
W	bottom flow
$1,\ldots,N$	plate index

Superscripts

c	common
opt	optimum
α	column index
β	column index

lation can be found in books of Van Winkle (1967) and Wankat (1988).

Knapp and Doherty (1992) developed a new process, in which continuous pressure swing distillation was combined with entrainer addition. The possibility of the application of an entrainer for the separation of binary azeotropic mixtures increases to a large extent the number of mixtures separable by this process. On the other hand the separation of the original components from the entrainer means an additional task.

Phimister and Seider (2000) were the first who studied the batch application of binary PSD by simulation. They investigated the separation of a minimum azeotrope (THF–water) by semi-continuous PSD and reverse-batch operation (batch stripping). They also investigated the control and other practical aspects of these configurations.

To our knowledge Repke, Klein, Bogle, and Wozny (2007) were the first, who investigated experimentally the application the pressure swing distillation in batch which was operated in open mode. They studied the separation of a minimum boiling, homoazeotropic mixture (acetonitrile–water) by pressure swing distillation in a batch rectifier and in a stripper with pilot-plant experiments and rigorous simulations.

Luyben (2005) compared the pressure swing and extractive distillation methods for methanol recovery system in the TAME reactive distillation process. He presented a quantitative steady-state and dynamic comparison of the pressure swing process (separation i-pentane–acetone) with an extractive distillation process (by applying water as solvent).

Luyben (2008a) compared the continuous extractive distillation and pressure swing distillation for the separation acetone–methanol. Steady-state designs and control structures are also developed for the two methods when the columns are heat integrated.

Luyben (2008b) investigated the design and control of a fully heat-integrated pressure swing azeotropic continuous distillation system for the separation THF–water.

Modla and Lang (2008) studied the feasibility of pressure swing batch distillation (PSBD) of binary mixtures (forming minimum or maximum azeotrope) in different column configurations. They suggested two novel configurations containing two rectifying (double column batch rectifier, DCBR) or two stripping sections (double column batch stripper, DCBS). The double column systems were operated in open mode (with continuous withdrawal of products (distillate/bottoms)). They made rigorous simulation calculations for the different column configurations, as well. The different configurations were compared for a given set of operational parameters. The best results were obtained with the two new double column configurations. They stated that these new configurations may provide a lot of advantages against the well-known simpler configurations (batch rectifier or stripper). For separating minimum azeotropes they suggested the application of double column batch stripper or batch stripper and for maximum azeotropes double column batch rectifier or batch rectifier, respectively.

Modla, Lang, and Denes (2010) studied the feasibility of the pressure swing batch distillation separation of ternary homoazeotropic mixtures in different single and double column configurations. In that paper the separation of the most frequent types of ternary mixtures were investigated.

Kopasz, Modla, and Lang (2009) presented a simple scheme for the control of product compositions (temperatures of bottoms product are controlled and their flow rates are manipulated) for double column batch stripper, for separating a binary minimum boiling point azeotropic mixture by pressure swing batch distillation.

Modla and Lang (2010) investigated the double column batch stripper in open mode for separation of acetone–methanol pressure sensitive azeotropic mixture. The two columns were thermally integrated to save energy. The energy demand was converted to CO_2 emission. They stated that the CO_2 emission can be reduced by 42% with the thermal integration of the two columns.

The goals of this paper are:

- To suggest two new double column systems operated in closed mode for pressure swing batch distillation.
- To investigate these configurations by feasibility studies and by rigorous simulation based on much less simplifying assumptions.
- To study the influence of the most important operational parameters.
- To compare the performance of open and closed modes of the double column systems.