Chemical Engineering and Processing 84 (2014) 71–81

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Hydraulic design, technical challenges and comparison of alternative configurations of a four-product dividing wall column

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ARTICLE INFO

Article history:
Received 18 January 2014
Received in revised form 14 March 2014
Accepted 17 March 2014
Available online 3 April 2014

Keywords:
Distillation
Dividing wall columns
Multi-partition columns
Aromatics

ABSTRACT

This study addresses technical feasibility related aspects of multi-partition wall alternatives for a four-product dividing wall column, which, although highly beneficial, have not been yet attempted in industrial practice. Utilizing an industrially relevant aromatics processing plant case as basis for design and evaluation of cost-effectiveness of alternative configurations, this paper focuses on the hydraulic design and dimensioning of a minimum energy configuration with two overhead product streams. DWC technology related issues are discussed, which can help to distinguish what makes sense and what not when dealing with practical implementation of multi-partition wall configurations.

1. Introduction

Striving towards greater sustainability drives the process industries to look for opportunities to improve the energy efficiency of distillation columns and sequences. Numerous academicians and practitioners are active in this field and utilize various approaches to provide theoretically sound conceptual, technology advancing solutions. Most of the academic effort is spent on column sequencing and heat coupling and in the literature there is every year a considerable number of publications introducing advances in this respect. These efforts are summarized in a book by Kiss, published last year [1]. However, few papers are concerned with finding adequate technical solutions that could be implemented in industrial practice in a cost-effective way.

A real technology breakthrough in this respect occurred recently by successful industrial implementation of so-called “dividing wall column” (DWC), i.e. a fully thermally coupled, single shell distillation column that minimizes energy and capital requirement as well as plot area, compared to that required by conventional two column sequences for obtaining three pure products [2–4]. Although DWCs are a proven technology, designers and users, confronted with increased complexity and related uncertainties, still hesitate to make the next, highly rewarding step, i.e. to build and operate DWCs with four products.

A conventional sequence for obtaining four specified products from a multicomponent aromatics plant feed (see Table 1) is shown in Fig. 1a [5]. In an alternative new design, this particular sequence could be replaced by a combination of a three-product DWC and a conventional column as shown in Fig. 1b. Some other possibilities are mentioned in a paper by Errico et al. [6]. However, this is of little relevance here, and the configuration shown in Fig. 1b is considered just as an example of an appropriate intermediate solution, because a four-product DWC is without doubt the most beneficial configuration for this separation task [5]. A partial confirmation is provided by Kiss et al. [7], who show that a conventional column combined with a single-partition, four-product DWC (so called “Kaibel column”) requires less energy for separation of a five component aromatics mixture into five products than any conventional or other sequences, including two conventional DWCs connected in series.

The first packed, single-partition wall, four-product DWC was taken into operation in 2002 in a BASF SE plant [8]. This configuration (denoted “2-4”), shown in Fig. 2a, is less efficient than its fully thermally coupled equivalent (“2-3-4”) shown in Fig. 2b. Namely, in such a case a certain amount of component remixing occurs in between two side- product draw-offs on main column side leading to undesired entropy formation. To avoid this, i.e. to implement a full (Petlyuk) thermal coupling, three sections need

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http://dx.doi.org/10.1016/j.cep.2014.03.009
0255-2701/

Table 1
Base case feed and product streams specifications.

Stream name	Feed (F)	C5-C6 (A)	BRC (B)	Toluene (C)	Heavies (D)
Flow rate [t/h]	31.7	7.45	3.87	7.97	12.44
Mass fractions (rounded)					
n-Butane	0.019	0.083	–	–	–
i-Pentane	0.064	0.273	–	–	–
n-Pentane	0.045	0.193	–	–	–
2-Methylpentane	0.080	0.341	0.003	–	–
N-Hexane	0.043	0.098	0.160	–	–
Benzene	0.086	0.013	0.675	–	–
3-Methylhexane	0.020	–	0.162	0.002	–
Toluene	0.247	–	–	0.984	0.001
Ethylbenzene	0.035	–	–	0.006	0.086
p-Xylene	0.042	–	–	0.003	0.107
m-Xylene	0.122	–	–	0.005	0.307
o-Xylene	0.055	–	–	–	0.140
m-Ethyltoluene	0.047	–	–	–	0.120
1-3-5-Trimethylbenzene	0.077	–	–	–	0.197
1-4-Diethylbenzene	0.017	–	–	–	0.043

to be arranged in parallel in the central part of the column shell, as shown schematically in Fig. 2b. A packed version of a DWC with a “2-3-4” configuration could be installed using available know-how and proven non-welded partition wall technology [5,9]. A major concern related to design and operation of such a complex DWC stems from the need to arrange properly and maintain during operation three vapour splits, while the “2-4” configuration requires only one.

Hydraulic design is the key to arranging required liquid to vapour flow rate ratio (L/V) on both sides of partition wall in each of partitioned sections. In other words, during design the vapour flow resistances in the parallel sections, for given liquid loads and packed bed heights, need to be arranged carefully to ensure obtaining the required vapour splits. For single and multi- partition DWCs, this can be done using methods described in detail elsewhere [10,11].

The problem is to maintain stable situation, because, local pressure drop disturbances may propagate and force the vapour splits to change and detrimentally affect the separation performance. A corrective action could be imposed by adjusting the liquid splits in a co-ordinated way. This is effective, and sensitivity in this respect should be examined by process simulation studies. The results of dedicated process control studies, performed using experimentally validated predictive models, indicate that both a single partition wall (“2-4”) and a complex three partition walls four-product column (“2-3-4”) could be controlled in an effective way [12–15].

Related malperformance risks could be lessened significantly if one of the required vapour splits could be avoided. As elaborated in detail elsewhere [16], a *Vmin*-diagram based analysis revealed a number of possibilities in this respect. Two simpler internal configurations, where in both cases one vapour split is eliminated and which exhibit the same performance and are thermodynamically equivalent to fully thermally coupled “2-3-4” DWC, have been identified and evaluated in detailed simulations carried out using commercial software package CHEMCAD [16,17]. The configuration on the left-hand side of Fig. 3 is referred to as (“s-2-3-4”), because it represents a simplified version of the “2-3-4” configuration. Here the middle and the main column sections are separated by a single, long partition wall, with only a fraction of the liquid going from the middle to the main column section side. The so-called (“2-2-4”) configuration, shown on right hand side of Fig. 3, employs two liquid splits and two vapour splits. This even simpler version of a four-product DWC contains only a short segment of total height arranged as three sections in parallel.

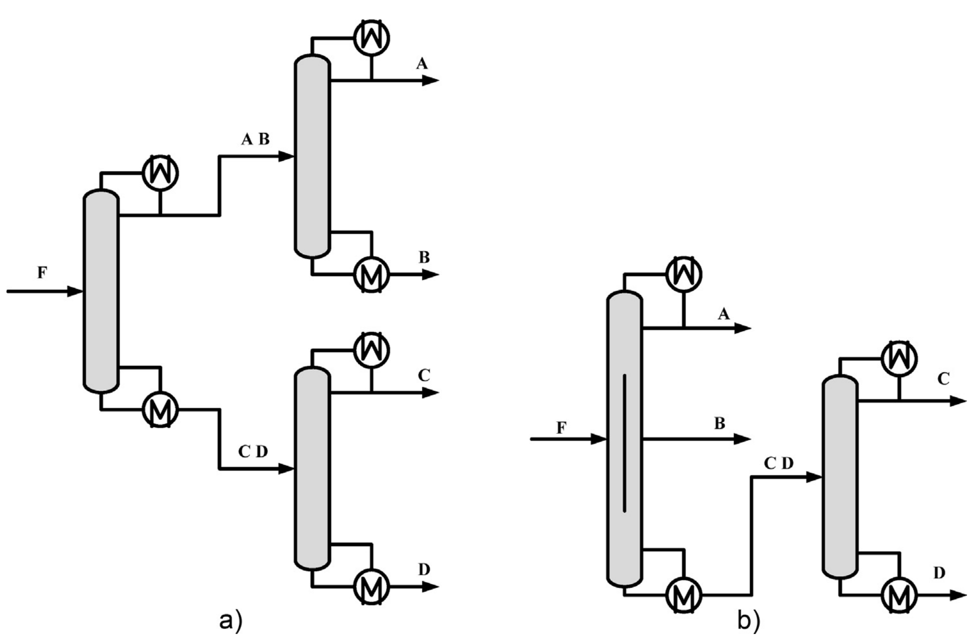

Fig. 1. Schematic representation of a conventional three-column sequence and an alternative configuration employing a three-product DWC connected in series with a conventional distillation column (CC).