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A novel simplified configuration for an ideal heat-integrated distillation column (ideal HIDiC)

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ABSTRACT

Although the ideal heat-integrated distillation column (ideal HIDiC) is much more thermodynamically efficient than its conventional analogues, its applications in the chemical and petrochemical process industries have been restrained due to the great difficulties and complexities in the design and implementation of internal heat integration between the rectifying section and the stripping section. For the avoidance of these difficulties and complexities, a novel simplified configuration for the ideal HIDiC, termed the SIHIDiC, is proposed and studied in this paper. Only three internal heat exchangers are used to approximate the internal heat integration, and their locations and sizes are key decision variables for process synthesis and design and should be considered to enhance thermodynamic efficiency in process development. A simple stepwise procedure is thus derived for process synthesis and design, and the SIHIDiC is then evaluated through intensive comparison with conventional distillation columns and the ideal HIDiC in terms of the separations of ethylene/ethane and benzene/toluene binary mixtures. The results obtained indicate that the SIHIDiC could be an excellent candidate to approximate the ideal HIDiC with reduced capital investment and somewhat similar (if not smaller) operating cost. The SIHIDiC offers essentially a much simpler way than the current available methods to design and implement the concept of the ideal HIDiC into separation processes.

1. Introduction

Internal heat integration between rectifying section and stripping section has been proved to be an effective way for the enhancement of thermodynamic efficiency of a conventional distillation column [1–5]. The ideal heat-integrated distillation column (ideal HIDiC) is such a kind of process that is created through the stage-to-stage internal heat integration between the whole rectifying section and the whole stripping section of a simple distillation column (Fig. 1). Both theoretical and (bench-scale and even pilot-plant) experimental studies have definitely confirmed that it could be much more thermodynamically efficient than its conventional analogues especially in the separation of close-boiling binary and multi-component mixtures [6,7]. In spite of the encouraging outcomes, the ideal HIDiC has not yet found wide applications in the chemical and petrochemical process industries, and one of the primary reasons lies on the arrangement of internal heat integration between the whole rectifying section and the whole stripping section because of the quite limited space within the column shell, the consequent difficulties and complexities in process synthesis and design, and the possibly strong influences to the mass transfer between the liquid and vapor phases. For the facilitation of the design and implementation of the ideal HIDiC, it is therefore imperative to devise a simple and yet easy-to-apply heat transfer mechanism between the rectifying section and the stripping section.

As far as the schemes for internal heat transfer between the rectifying section and the stripping section are concerned, there have been a lot of attempts conducted so far. Tung et al. [8] developed a plate-fin device for the heat transfer between the parallel vertical flows of the alternating stripper and rectifier layers. Hugill [9] attempted to use a plate-fin heat exchanger (PFHE) for the heat transfer between the rectifying section and the stripping section for a lab-scale experimental device. The PFHE consisted of many parallel flat plates and intermediate corrugated plates (fins). While the flat plates separated the process streams and worked as the primary heat transfer surface, the fins served as the secondary heat transfer surface. The HIDiC thus constructed has a high energy saving potential. Naito et al. [6] adopted a vertical shell and tube heat exchanger to accommodate the ideal HIDiC. Their design incorporated only one tube and one shell, with the former as the rectifying section and the latter as the stripping section, and the surface of the tube acted as the effective heat transfer area. Kaeser and Pritchard [10] developed a sieve tray with its surface as the effective heat transfer

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Nomenclature

C	utility cost ($\$\,\mathrm{kJ}^{-1}$)
CDiC	conventional distillation column
CI	capital investment ($)
D	diameter (m)
F	feed flow rate ($\mathrm{kmol\,h}^{-1}$)
F_S	vapor flow rate at the top of the stripping section ($\mathrm{kmol\,s}^{-1}$)
H	height (m)
H_1	location of the top internal heat exchanger in the rectifying section
H_2	location of the top internal heat exchanger in the stripping section
H_3	location of the intermediate internal heat exchanger in the rectifying section
H_4	location of the intermediate internal heat exchanger in the stripping section
H_5	location of the bottom internal heat exchanger in the rectifying section
H_6	location of the bottom internal heat exchanger in the stripping section
HIDiC	heat-integrated distillation column
L	liquid flow rate ($\mathrm{kmol\,h}^{-1}$)
M_W	molecular weight of a mixture ($\mathrm{g\,mol}^{-1}$)
N	number of stages
OC	operating cost ($\$\,\mathrm{yr}^{-1}$)
P	pressure (kPa)
Q	heat duty (kW)
S_1	heat transfer area of the top internal heat exchanger (m^2)
S_2	heat transfer area of the intermediate internal heat exchanger (m^2)
S_3	heat transfer area of the bottom internal heat exchanger (m^2)
SIHIDiC	simplified ideal heat-integrated distillation column
T	temperature (K)
ΔT	temperature difference (K)
TAC	total annual cost ($\$\,\mathrm{yr}^{-1}$)
U	overall heat transfer coefficient ($\mathrm{kW\,K}^{-1}\,\mathrm{m}^{-2}$)
V	vapor flow rate ($\mathrm{kmol\,h}^{-1}$)
V_{NT}	maximal vapor flow rate ($\mathrm{mol\,s}^{-1}$)
x	liquid composition
y	vapor composition
z	feed composition

Greek letters

β	payback period (yr)
ε	tolerance error
λ	size of adjustment

Superscripts

0	initial value
k	iteration number
sp	product specification

Subscripts

bot	bottom of a distillation column
CON	condenser
F	feed
FPH	feed pre-heater
FPC	feed pre-cooler
HI	heat-integrated
r	rectifying section
REB	reboiler
s	stripping section
top	top of a distillation column

area. Olujic et al. [11,12] advocated using heat transfer panels (elements), and they also suggested that internal heat transfer should be arranged with increasing/decreasing column diameters, which should be determined based on the flood limits. Recently, Gadalla et al. [13] presented a brief account of four configurations for internal heat transfer between the rectifying section and the stripping section. The first was a multi-tube configuration, where the recti-

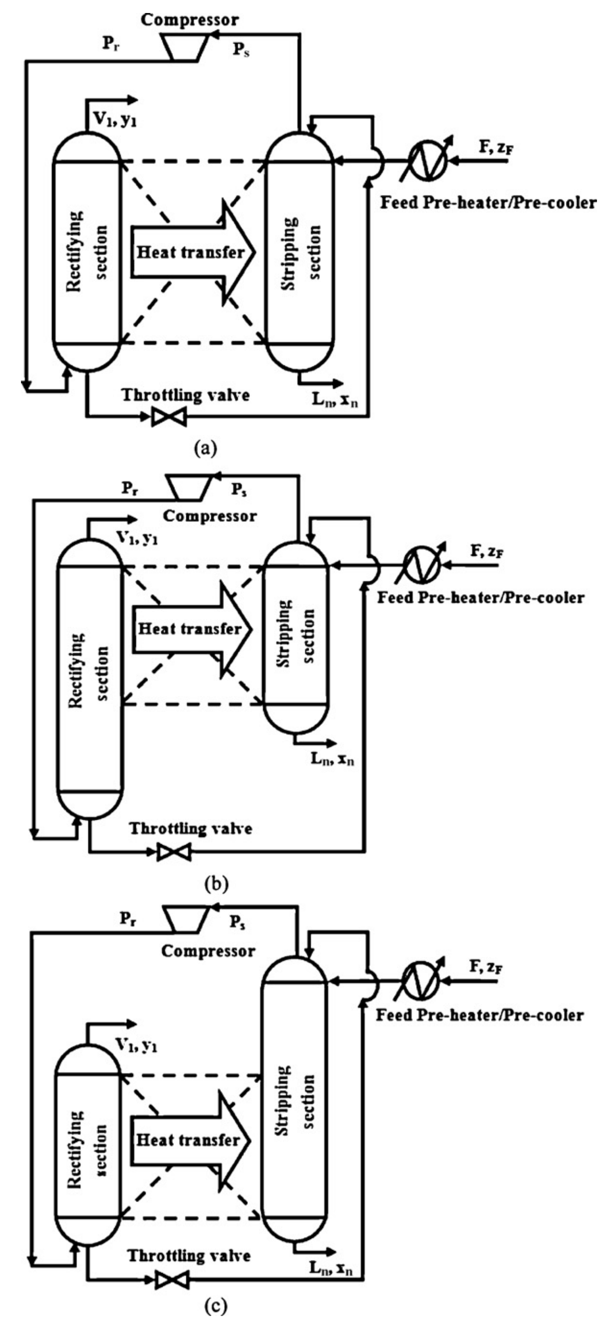

Fig. 1. Schematics of an ideal HIDiC: (a) a symmetrical ideal HIDiC, (b) an asymmetrical ideal HIDiC (ideal HIDiC_upper), and (c) an asymmetrical ideal HIDiC (ideal HIDiC_bottom).