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Energy conserving effects of dividing wall column☆

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ABSTRACT

The energy-conserving performance of dividing wall column (DWC) is discussed in this paper. The heat transfer through the dividing wall is considered and the results are compared with that of common heat insulation dividing wall column (HIDWC). Based on the thermodynamic analysis of heat transfer dividing wall column (HTDWC) and HIDWC, both computer simulation and experiments are employed to analyze the energy-conserving situation. Mixtures of *n*-hexane, *n*-heptane and *n*-octane are chosen as the example for separation. The results show that the energy consumption of HTDWC is 50.3% less than that of conventional distillation column, while it is 46.4% less than that of HIDWC. It indicates that DWC is efficient on separating three-component mixtures and HTDWC can save more energy than HIDWC. Thus it is necessary to consider the heat transfer while applying DWC to industry.

1. Introduction

Distillation is one of the most important and popular technologies for separation of multicomponent mixtures in chemical and petrochemical industries. However, high energy-consumption and relatively low thermodynamic efficiency severely limit the development of distillation [1]. Therefore, reducing the energy consumption is an urging motivation for studying distillation column [2–6]. On this premise, a series of complex distillation column sequences have been designed and widely used in industry, such as column with side rectifier or side stripper, thermally coupled distillation column, and dividing wall column (DWC, Fig. 1). Typically a dividing wall column operated under optimum conditions can save about 30% energy compared with a conventional column sequence [7]. Furthermore, it could be used within a single shell by installation of a divided wall to separate the prefractionation from the main column section [5,8,9], so the system can save up to 30% on capital investment compared to conventional equipment [10–12].

DWC can be applied to separate many systems, such as hydrocarbons, alcohols, aldehydes, ketones, and esters. However, due to the complexity in calculation and control, it took a long time to be applied. DWC was first used in industry in 1985. At present, most of the operational DWCs belong to BASF company, such as the DWC used to recycle 1-hexene from gasoline mixture of Sasol company in South Africa, which is also the highest DWC in the world with a height of 107 m and a diameter of 5 m [13]. With the increase of energy cost, Sulzer, Koch-Gitsch, Kellogg, Linde, Uhde, Sumitorm and some other companies have also developed and applied DWC techniques. The number of DWC in industrial production is increased to nearly 300 in 2010 from less than 20 in 2000. The production practice manifests that the application of DWC has achieved great economic benefit.

In the recent study of DWC, most researchers ignore the heat transfer between the prefractionation and the middle section of the main column for simplification. However, the heat transfer is usually significant due to the temperature difference between two sides of the wall. Hence, it is important to know the effect of heat transfer on the energy-saving situation of DWC [13,14]. In this study, the elimination of back-mixing in DWC is validated, which is important for energy-saving. Then the influence of heat transfer through the wall on the energy efficiency of DWC is investigated by changing the composition of the feed.

2. The Structure of Dividing Wall Column

Conventionally, the separation of a three-component mixture requires a sequential system with at least two columns, while DWC can accomplish this task in one column. Generally a DWC looks like a common distillation column with a side-draw. The column has a vertical separating wall with certain length, which distinguishes the “pre-fractionating” region [*e.g.* the left part in Fig. 1(a)] and the “main column” region [*e.g.* the right part in Fig. 1(b)] [15–19]. The feed in the prefractionator is a mixture of three components, A, B and C, where A is the lightest component and C is the heaviest component based on the boiling points. In a DWC, the prefractionator first performs a sharp split between A and C, while allowing B to distribute in both streams. The streams of AB and BC from the two ends of the prefractionator enter the main column,

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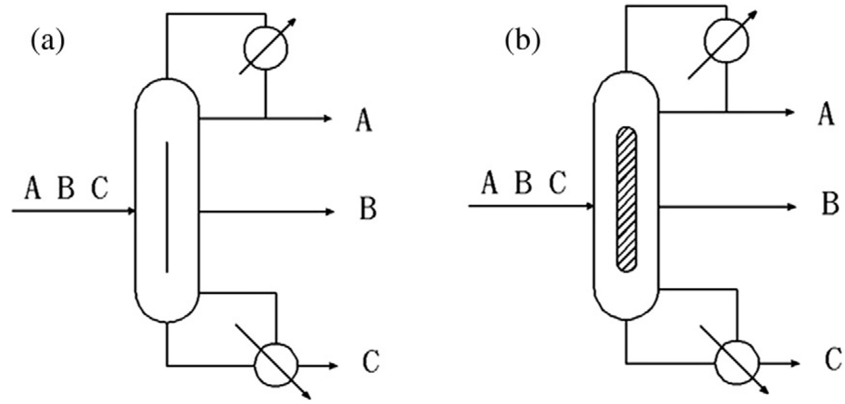

Fig. 1. Heat insulation dividing wall column (HIDWC) (a) and heat transfer dividing wall column (b).

where components A and B are separated in the upper portion while components B and C are separated in the lower portion. Finally products A and C are collected at the top and the bottom of DWC separately, while product B gathers in the central column with the maximum concentration. In the process, the reflux liquid from the condenser and the vapor from the reboiler of the main column split on both sides of the separating wall, offering energy for the prefractionator region. Thus the bottom reboiler and overhead condenser in prefractionator can be omitted. The main advantages of DWC are lower capital investment, smaller operation area and lower energy consumption compared with conventional separation sequences. For instance, a distillation column and some ancillary equipment, such as reboilers, condensers, overhead reflux pumps and piping, can be omitted in DWC [16,19–21]. If the heat transfer across the dividing wall is negligible, DWC is thermodynamically equivalent to the Petlyuk column, and the corresponding structure is called heat insulation dividing wall column (HIDWC) as shown in Fig. 1(b). If the heat transfer is considered, the structure is named heat transfer dividing wall column (HTDWC) as shown in Fig. 1(a). Both types of DWC are analyzed in this paper.

3. Thermodynamic Properties

3.1. Thermodynamic properties of conventional separation sequences

There are two conventional separation sequences for three-component mixtures as shown in Fig. 2. In the direct sequence, column 1 is used to produce the lightest component A at the top, while the mixture of components B and C is separated in column 2 [Fig. 2(a)]. In the indirect sequence, component C is collected at the bottom of column 1, and components A and B are concentrated at the top and bottom of column 2 separately [Fig. 2(b)]. The concentration of each product is higher than 98% by the two steps of separation.

A distillation column can generally be described as an energy converter. Energy supply is usually necessary in order to separate a mixture to its pure components. The energy is supplied by feed materials and reboiler, while the energy is removed with products and condenser [22]. The thermodynamic analysis to DWC is based on the first and the second laws of thermodynamics,

$$Q_{\mathrm{REB1}}-Q_{\mathrm{CON1}}+Q_{\mathrm{REB2}}-Q_{\mathrm{CON2}}+FH_{\mathrm{F}}-DH_{\mathrm{D}}-SH_{\mathrm{S}}-BH_{\mathrm{B}}=0 \quad (1)$$

$$\Delta S=\frac{Q_{\mathrm{CON1}}}{T_{\mathrm{CON1}}}-\frac{Q_{\mathrm{REB1}}}{T_{\mathrm{REB1}}}+\frac{Q_{\mathrm{CON2}}}{T_{\mathrm{CON2}}}-\frac{Q_{\mathrm{REB2}}}{T_{\mathrm{REB2}}}-FS_{\mathrm{F}}+DS_{\mathrm{D}}+SS_{\mathrm{S}}+BS_{\mathrm{B}}\geq 0. \quad (2)$$

The energy loss (W_{Loss}) inside the column is caused by the irreversible mass transfer and heat transfer processes,

$$\begin{aligned} W_{\mathrm{Loss}}=T_0\Delta S=\ & Q_{\mathrm{REB1}}\left(1-\frac{T_0}{T_{\mathrm{REB}}}\right)-Q_{\mathrm{CON1}}\left(1-\frac{T_0}{T_{\mathrm{CON}}}\right) \\ & +Q_{\mathrm{REB2}}\left(1-\frac{T_0}{T_{\mathrm{REB}}}\right)-Q_{\mathrm{CON2}}\left(1-\frac{T_0}{T_{\mathrm{CON}}}\right)-W_{\min} \end{aligned} \quad (3)$$

where $W_{\min}$ is the minimum work to separate the mixture given by the following equation

$$\begin{aligned} W_{\min} &= F(H_{\mathrm{F}}-T_0S_{\mathrm{F}})-D(H_{\mathrm{D}}-T_0S_{\mathrm{D}})-S(H_{\mathrm{S}}-T_0S_{\mathrm{S}})-B(H_{\mathrm{B}}-T_0S_{\mathrm{B}}) \\ &= (DH_{\mathrm{D}}+SH_{\mathrm{S}}+BH_{\mathrm{B}}-FH_{\mathrm{F}})-T_0(DS_{\mathrm{D}}+SS_{\mathrm{S}}+BS_{\mathrm{B}}-FS_{\mathrm{F}}) \\ &= \Delta H-T_0\Delta S. \end{aligned} \quad (4)$$

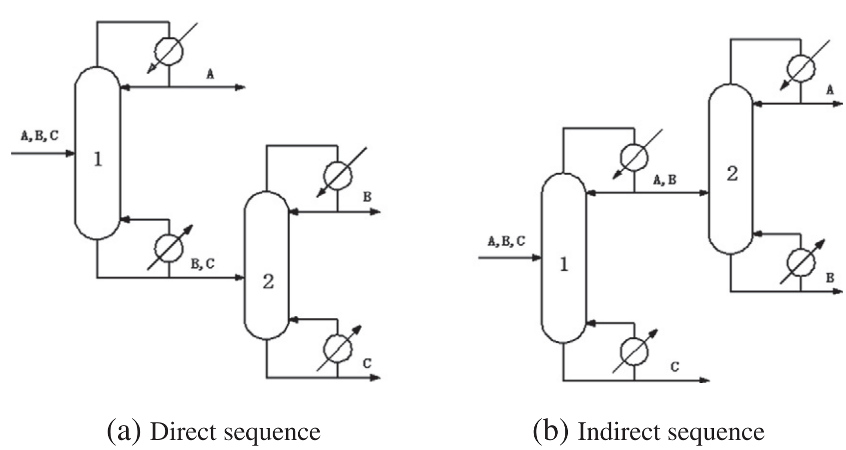

Fig. 2. Conventional separation sequence for three-component mixtures.