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Research Paper

A thermally coupled dividing tower batch rectifier: Energy consumption and cost

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HIGHLIGHTS

- A dividing tower batch rectifier is proposed.
- Thermal coupling is made between two divided sections.
- Variable manipulation policy is formulated for controlled dynamics.
- This scheme is illustrated by the batch processing of a binary wide boiling system.
- Performance evaluation is made in terms of energy and cost savings.

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ABSTRACT

In this contribution, a thermally coupled dividing tower batch rectifier (TCDTBR) is proposed. Aiming to boost the fuel efficiency and economic performance, the cylindrical shell of the batch column is horizontally divided into two diabatic sections. A compressor is installed in such a way that one section operates at sufficiently higher pressure than the other one to create a positive thermal driving force between them for feasible heat exchange. The internal heat integration between these two coupled sections in TCDTBR arrangement can be accomplished by using the sequential heat exchangers in the trays. Proposing a variable manipulation policy, this thermal intensification mechanism is demonstrated by a batch rectifier that separates a binary mixture of wide boiling constituents, showing a substantial improvement in both fuel consumption (i.e., energy) and cost savings. Finally, the proposed TCDTBR has shown its superiority over an existing heat integrated batch rectifier with a jacketed reboiler (HIBRJR) on the same example system.

1. Introduction

Distillation has an extensive application as a separation unit in chemical and petroleum industries, among others. It shares about a 3% of the total energy consumed in the world. Fossil fuels are the principle source of heat used in industrial practice to meet the energy demand of the fractionating columns. It is quite surprising that the maximum second law efficiency attained in a classical distillation is around 20% [1]. To enhance the fuel efficiency of this separation unit, the heat integration concept first came into notice almost 80 years back [2]. In recent times, this research area has been revived because of several factors: fluctuating fossil fuel prices, declining rate of petroleum reserves, increasing concentration of greenhouse gases and political uncertainty in many oil-rich countries.

Several studies reported so far on thermal intensification have dealt with the continuous flow distillation columns. In this regard, first of all, reactive distillation [3] comes in our mind. Other notable schemes include the dividing wall column (DWC) [4], direct vapor recompression column (VRC) [5] and internally heat integrated distillation column (HIDiC) [6]. It is interesting to note that the first two column configurations (i.e., DWC and VRC) are being used in industrial practice, while the last one (i.e., HIDiC) is at the final stage of testing.

In 1998, Takamatsu et al. [7] first proposed a configuration of a thermally integrated batch distillation scheme that comprises of a column shell surrounded by a reboiler as a jacket. Subsequently, Maiti and Jana [8] validated the idea and extracted the merits and demerits of this thermally integrated scheme. Recently, an externally energy intensified batch rectifier is devised by Jana and his co-workers [9] under the name of 'variable speed' vapor recompressed batch distillation (VRBD). In that configuration, the

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vapor recompression system works in conjunction with a compressor operated in variable speed mode. Numerical simulation showed that the VRBD leads to a significant fuel and cost savings. Most recently, the heat pump assisted bottom flashing scheme [10] is developed for batch processing.

As far as HIDiC is concerned, as stated, it is extensively studied for continuous distillation column [11]. However, recently there is a work reported [12] exploring the feasibility of this configuration in batch stripping that occurs at transient state, which makes the process operation and control a challenging task.

In this communication, a thermally coupled dividing tower batch rectifier (TCDTBR) is introduced. The idea is to reduce the external fuel inputs by effectively utilizing the internal heat source and to distribute the heat more uniformly along the length of the two divided sections. Formulating a variable manipulation policy, we aim at exploring the energetic and economic benefits to be obtained by the proposed unsteady state TCDTBR system by using a simulated batch rectifier. Finally, we investigate the superiority of the proposed dividing tower over an existing heat integrated batch rectifier with a jacketed reboiler (HIBRJR) [13] with reference to a classical standalone column.

2. Thermally coupled dividing tower batch rectifier: the proposed scheme

2.1. Configuration and operating principle

The operating principle of a thermally coupled dividing tower batch rectifier (TCDTBR) is highlighted in Fig. 1. This configuration is proposed by horizontally dividing the shell of the classical batch distillation into two diabatic sections, namely the top rectifier and bottom rectifier. The diabatic section typically allows heat transfer to enter or leave its trays [14]. It is evident from the TCDTBR structure that the bottom rectifier includes the trim-reboiler and the top one has the trim-condenser. Instead of having heat rejection only through the trim-condenser and heat supply through the trim-reboiler, the total heat rejection is made through distributing it along the top rectifier, while the bottom rectifier aims to absorb that heat with similar distribution along the column.

A compressor is mounted over the bottom rectifier so that the top rectifier pressure becomes high enough to create a positive thermal driving force between two diabatic sections for feasible heat exchange. At this point, it should be highlighted that no superheating/subcooling of vapor stream in the compressor is considered. However, the vapor temperature attained in the compressor is considered as the saturation temperature of the exiting vapor from the compressor.

On the other hand, to depressurize the bottom liquid leaving the top rectifier, a throttling valve is installed. The internal heat transfer between two diabatic sections in TCDTBR arrangement can be accomplished by using sequential heat exchangers in the trays.

For the thermally coupled structure, the internal heat exchange from top to bottom rectifier (Q_I) is computed using the term $UA\Delta T$, where U is the overall heat-transfer coefficient, A the heat-transfer area, and ΔT the thermal driving force between the two coupled trays. As shown in Fig. 1, in the TCDTBR scheme, a typical nth stage of bottom rectifier is paired with $n_t - 1$th stage of top rectifier. Accordingly, we have the general form as:

$$Q_{I,n} = UA(T_{n_t-1} - T_n) \tag{1}$$

Here, T represents the tray temperature. By applying this mechanism, a certain amount of energy is likely to transfer from the top rectifier to the bottom one through the internal heat exchangers and brings the liquid flow (L) for the former section and vapor flow (V) for the latter one. Now the respective equations are given below to compute the internal fluid rates as:

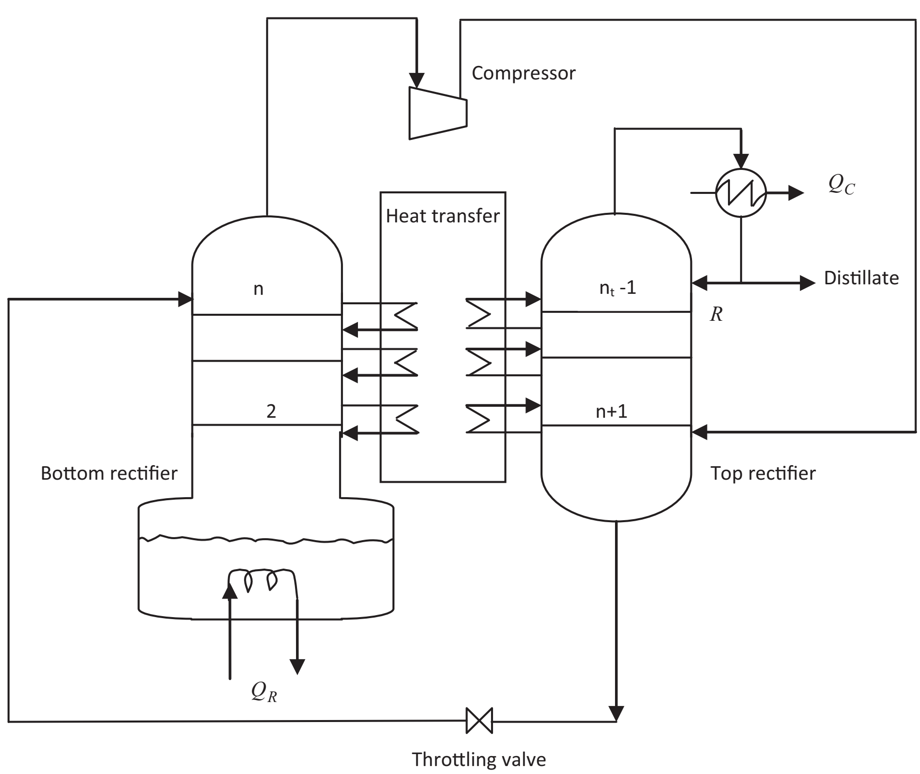

Fig. 1. Schematic representation of the proposed thermally coupled dividing tower batch rectifier (R = reflux rate, Q_R = reboiler duty, and Q_C = condenser duty).