Applied Energy 211 (2018) 1261–1281

Contents lists available at ScienceDirect

Applied Energy

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

Recently developed heat pump assisted distillation configurations: A comparative study

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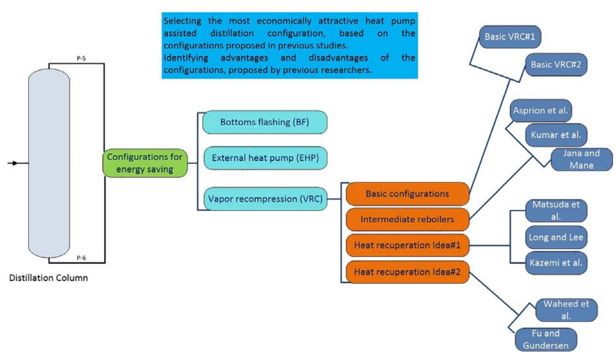
HIGHLIGHTS

- 18 previously proposed configurations of VRC, BF and EHP were studied.
- All the configurations were designed for propylene-propane separation.
- A comparative study among various configurations was carried out.
- Advantages and disadvantages of each configuration were identified.
- Based on energy and costs savings, the most attractive configurations were identified.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Distillation
Energy
Costs
Vapor recompression
Heat pump

ABSTRACT

Various configurations of vapor recompression (VRC), bottoms flashing (BF) and external heat pump (EHP) for energy and/or costs savings were proposed in literature. Based on published studies, the best configuration for having the highest performance among the proposed separation systems cannot be easily identified by process engineers as the basis for comparison were not the same. In this study, a comparative study was carried out among the most recent configurations of VRC, BF, EHP and two previously proposed ideas for thermal enhancement of VRC. Based on the schemes and ideas presented by previous researchers, 18 heat pump assisted configurations were designed for separation of propylene from a propylene-propane mixture. The highest total energy saving of 93.8% was identified upon application of a configuration, designed based on heat recuperation ideas. Based on the results of current research, the BF exhibited the best economic performance among the basic heat pump systems, while the external heat pump system exhibited the worst energy and economic performance compared to the other designs. The base conventional distillation column was found to have the lowest capital costs (15.6 mUSD), while a heat recuperated VRC system had the lowest annual operating costs (3.04 mUSD) and total annual costs (7.63 mUSD).

1. Introduction

Distillation is the most common technology for separation of chemicals [1]. Numerous studies were dedicated to improving energy performance of this system due to its high energy requirements [2–4]. Various systems were proposed for energy saving in distillation systems

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https://doi.org/10.1016/j.apenergy.2017.12.023
Received 19 August 2017; Received in revised form 16 November 2017; Accepted 1 December 2017
0306-2619/

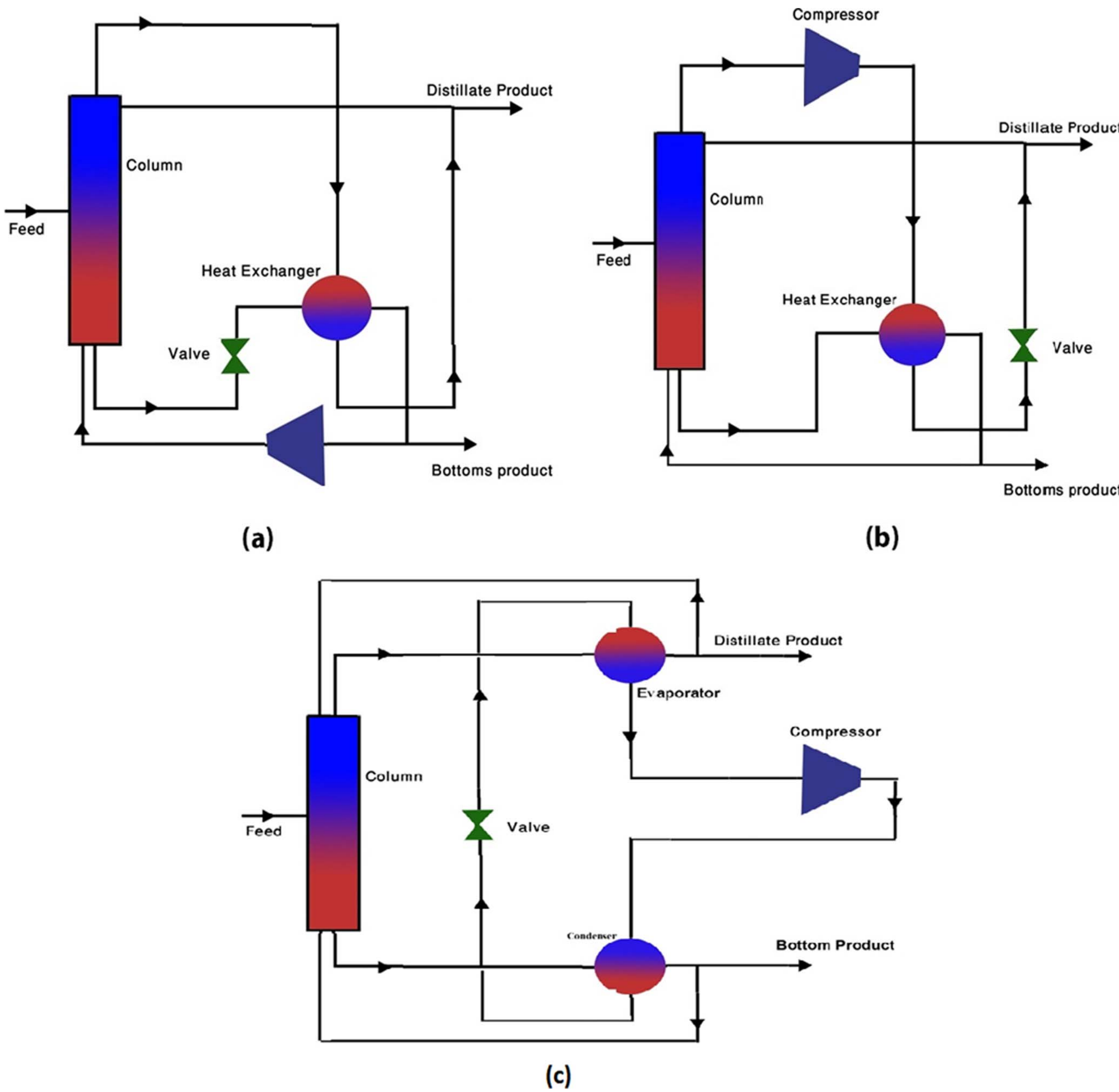

Fig. 1. Simplified process flow diagrams of (a) bottoms flashing (BF), (b) vapor recompression (VRC) [18] and (c) external heat pump (EHP) assisted distillation systems [14].

[5–7]. These systems include vapor recompression (VRC) [8–10], bottoms flashing (BF) [11–13], external heat pump assisted distillation (EHP) [1,14] and internally heat integrated distillation column (i-HIDiC) [15–17]. These systems were proposed based on the same concepts. In the condenser (rectifying section) of a distillation system, thermal energy is removed to provide the required reflux (QC). Also, in the reboiler (stripping section), thermal energy is supplied to have the require boil up (QH). Heat pump assisted systems were proposed based on this idea that QH can be supplied by QC. However, this heat transfer is not feasible through a regular operation in a distillation column as the temperature of rectifying section is lower the stripping section. A set of modifications is applied on conventional distillation systems to make this heat transfer feasible. Simplified process flow diagrams of VRC, BF and EHP systems are shown in Fig. 1 [14,18]. As shown in Fig. 1, all the configurations require compressors.

In VRC, pressure, temperature and dew point temperature of the top product are increased through compression, this compression process conditioning the required thermal energy transfer from rectifying to stripping section.

In BF, pressure, temperature and bubble point temperature of the bottom product are decreased through expansion. This expansion process makes feasible thermal energy transfer from rectifying to stripping section of distillation column.

In EHP an auxiliary liquid at a low temperature takes thermal energy of the top product and store it by changing of phase to vapor. By compression of formed vapor, its pressure, temperature and dew point temperature are enhanced, which supplies driving force for transfer of adequate thermal energy to the bottom product, for boiling up. In the next step, the auxiliary fluid is passed through an expansion valve to complete the cycle.

Also, the basic configurations of VRC and BF, presented in previous studies differ in details, e.g. VRC schemes in [19,20], and BF schemes in [21,22].

Numerous studies were dedicated to enhance performance of