Journal of Cleaner Production xxx (2014) 1–8

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Design and simulation of ethane recovery process in an extractive dividing wall column

Yadollah Tavan [a,*], Shahrokh Shahhosseini [b], Seyyed Hossein Hosseini [c]

[a] National Iranian Gas Company (NIGC), Tehran, Iran
[b] Process Simulation and Control Research Laboratory, School of Chemical Engineering, Iran University of Science and Technology, P.O. Box 16765-163, Narmak, Tehran, Iran
[c] Chemical Engineering Department, Faculty of Engineering, Ilam University, 69315-516 Ilam, Iran

ARTICLE INFO

Article history:
Received 9 May 2013
Received in revised form
1 March 2014
Accepted 3 March 2014
Available online xxx

Keywords:
Dividing wall column
Distillation
Separation
Simulation
Azeotropic process
Design

ABSTRACT

Separation of CO_2 from hydrocarbons in the natural gas is complicated due to the existence of an azeotrope between ethane and CO_2 at the cryogenic temperatures. The key issues to break this azeotrope are high investment costs for the unit equipments and the associated high energy requirements. Accordingly, an innovative process based on the dividing-wall column (DWC) technology is designed using short-cut methods and relevant rigorous simulations. The energy demand and some environmental factors such as CO_2 removal efficiency and CO_2 emission reduction are studied for the conventional and DWC processes. It is found that the process including DWC is a better choice than the conventional one from economical and environmental point of views. Remarkably, this technology reduces the energy demand up to 51.6%.

1. Introduction

The increase in global energy demand has led to widespread investigations on alternative sources of primary energy even at the most remote areas of the earth. Natural gas is the most sought, after liquid fuel source, due to its cleaner combustion and less flue gas emission into the atmosphere (Alfadala and Al-Musleh, 2009). Natural gas contains impurities such as carbon dioxide, hydrogen sulfide, carbon disulfide, mercaptans and sometimes traces of carbonyl sulfide. The removal of acid gases, H_2S and CO_2 from gas stream is essential due to environmental, operational and health reasons (Maddox, 1982). Generally, the acid gas pipeline specifications are 4.0 ppm H_2S and 2 vol% of CO_2 with the dew point of less than 263 K at 4500 kPa. Since H_2S is extremely corrosive and toxic, it is removed from the gas before its consumption. Apart from meeting customer's contract specifications and successful liquefaction process, removal of CO_2 from natural gas at high pressure has currently become a global issue (Tavan and Hosseini, 2013a). Despite several researches done on CO_2 capturing in chemical processes (Sun and Smith, 2013; Harkin et al., 2010; Câmara et al., 2013), the existence of the minimum boiling CO_2-ethane azeotrope in natural gas process could causes certain problems. High concentrations of carbon dioxide in natural gas occur when carbon dioxide is used for enhanced oil recovery. An azeotrope between ethane (C_2H_6) and CO_2 complicates separation of CO_2 from natural gas. Accordingly, using natural gas liquid (NGL) as extractive component, Lastari et al. (2012) proposed low temperature distillation process in a series of distillation columns. The system generates high pressure CO_2, pure ethane and some amounts of NGL. However, the conventional extractive distillation process typically includes two serial distillation columns. The main disadvantage of this separation process is its high capital investment and high amount of energy required to fulfill the desired purification. Therefore, to overcome this drawback, advanced intensification and integration process techniques such as thermally coupled distillation columns, dividing-wall columns (DWC), heat-integrated distillation columns and reactive distillation (RD) were employed (Yildirim et al., 2011). In a DWC, the middle section of a single vessel is split into two sections by inserting a vertical wall into an appropriate position of the column (Bravo-Bravo et al., 2010; Gutiérrez-Guerra et al., 2009). The DWCs have attracted more attention in the chemical industries recently due to separation of

* Corresponding author. Tel./fax: +98 21 88912525.
E-mail address: yadollahtavan@gmail.com (Y. Tavan).

http://dx.doi.org/10.1016/j.jclepro.2014.03.015
0959-6526/© 2014 Elsevier Ltd. All rights reserved.

more components in one single distillation unit, thereby saving both energy and capital costs. The theoretical studies have shown that DWCs could lead to at least 30% reduction in energy costs compared to conventional schemes (Sangal et al., 2012; Gómez-Castro et al., 2011). It is notable that DWC technology is not limited to ternary separations; it can also be used in azeotropic separations, extractive distillation, and reactive distillation (Kiss and Suszwalak, 2012a).

Although several researches have conducted about extractive dividing-wall columns (Ignat and Kiss, 2012; Sangal et al., 2014; Wu et al., 2013), the process being studied is different from conventional extractive distillation columns. In conventional extractive columns a third component is added to the system and solvent loss in the product streams requires a make-up stream; while in the present study, the solvent is a mixture of propane and heavier components (NGL) in which the solvent stream is quite similar to the light key (ethane). These distinct features of the process leads to some convergence problems. Furthermore, the present study has some advantages such as existence of no water in the solvent stream and accordingly non-corrosive behavior of the solvent as compared with conventional extractive processes. In addition, in order to reduce the energy requirements and number of trays in the extractive distillation process of separating the CO_2/ethane azeotrope, possibility of using DWC is examined by HYSYS3.1 (www.aspentech.com) for the first time using top-wall configuration. Furthermore, the rates of the interconnecting streams are optimized in order to minimize energy requirement of the process. Eventually, energy requirements and some environmental parameters of the novel DWC (improved) process and the conventional one are compared with each other to find a more beneficial process.

2. Simulation

2.1. Thermodynamic analysis of the extractive column

Several strategies have been used in industries in order to separate the azeotropic mixtures. Some of them require addition of a third chemical component for shifting the vapor–liquid equilibrium such as extractive distillation, which uses a higher boiling solvent and azeotropic heterogeneous distillation for entraining chemical component. Another method for breaking azeotropes, which does not require addition of a third component, is pressure swing azeotropic distillation, wherein two columns operate at two different pressures (Doherty and Malone, 2001; Luyben, 2013). The thermodynamic analysis should be done prior to choosing the best method for separating the azeotropes. For this purpose, a system containing CO_2/ethane and n-pentane as an agent of extraction is considered. CO_2 and ethane are dissimilar molecules and have different boiling points of −78 and −88 °C and molecular weights of 44 and 30 g/mol, respectively. These molecules have a strong repulsion towards each other which leads to existence of a minimum boiling azeotrope in the system as shown in Fig. 1(a, b). From the figure, the azeotrope compositions are 0.67 and 0.64 at 2400 and 1500 kPa, respectively. Therefore, the relative volatility of CO_2-ethane azeotrope does not significantly change with pressure and confirms that the pressure swing distillation is not appropriate for the present study. Fig. 1b clearly indicates that the phase envelope of the system drastically changes with n-pentane mole fraction. Furthermore, addition of n-pentane decreases CO_2 freezing temperature to −75.9 °C (preventing formation of solid CO_2). Therefore, using extraction distillation is a promising process for the present system. The residue curve of CO_2/ethane/n-pentane can be helpful in elucidating the distillation part. Accordingly, the residue curve map of the mixture at the pressure of 2400 kPa is illustrated in Fig. 2. As shown in Fig. 2, the ternary mixture presents a single

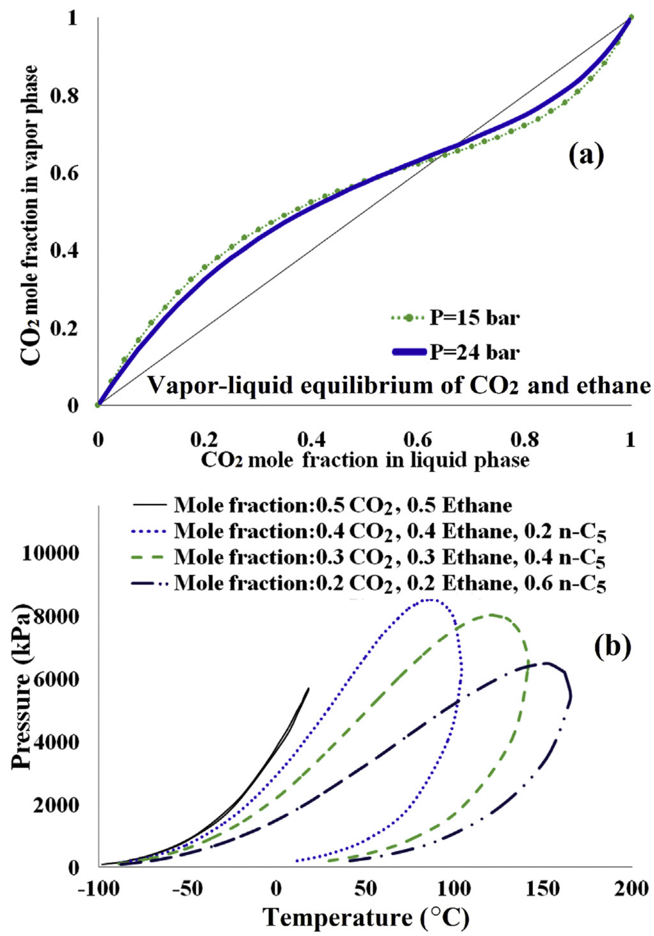

Fig. 1. The properties of CO_2-ethane azeotrope process in terms of (a) binary diagram and (b) phase envelope.

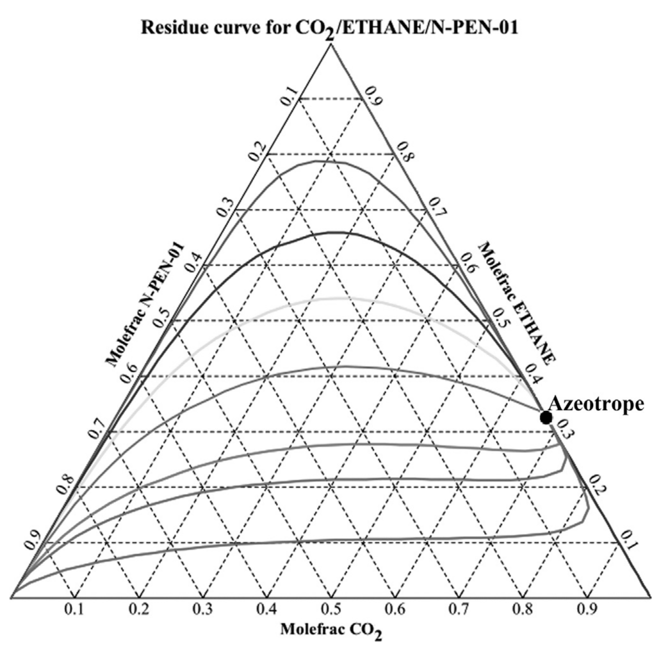

Fig. 2. The residue curve map of CO_2, ethane and normal pentane.

Please cite this article in press as: Tavan, Y., et al., Design and simulation of ethane recovery process in an extractive dividing wall column, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.03.015