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Feed-splitting technique in the extractive distillation of CO_2–ethane azeotropic process

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ABSTRACT

Separation of azeotropic mixtures is one of the most energy intensive systems in petrochemical industries. In the present study effect of feed-splitting on energy demand of the extractive distillation of CO_2–ethane azeotropic process is studied by means of Hysys process simulation software and relevant optimization analysis. Two alternatives are proposed for using feed-splitting technique in the process. The proposal presented in this work is splitting the feed before entering it to the heat exchanger in such a way of keeping a proper fraction of the feed at its original temperature and the rest being heated up with the warmer bottom product. A comparison between the results of the feed-splitting configurations and the conventional process in terms of total energy demand and environmental problems are carried out to determine the best scheme. It is observed that the best scheme of feed splitting technique in its optimized state leads to 56% reduction in energy demand in comparison with the conventional process.

1. Introduction

Throughout the chemical industry, the demand for purer products, coupled with relentless pursuit for greater efficiency, has necessitated continued research into the techniques of distillations [1]. Distillation is one of the oldest and most important separation processes used in the chemical and petrochemical industries. Therefore distillation is the process most targeted when the issue of energy consumption is addressed [2,3]. The distillation processes design in industrial practice is still conducted by heuristic simulations that require a detailed specification of design parameters [4]. It is well known that the base of distillation process is the difference in volatility of the components which should be separated. The easier separation with lower energy demand can be achieved if the higher relative volatility provided for the systems. In this regards, process integration has been known as a proper method for reducing the energy requirement. Although, several methods have been used for energy saving in distillation processes, preheating the feed (feed-splitting) is well known as a common procedure for saving energy in industrial distillation towers. In this method heating whole or a portion of the feed with one the column streams was introduced as an appropriate way for energy saving in "warm" distillation columns. With this heat integration technique, the decrease on waste of energy can be further improved and might highly contribute to reduce column energy requirement in optimized process heaters. Although, the theory of feed splitting was conceived to be easily applied to the revamping of an existing plant (requiring small capital investment by adding only one exchanger); there is a drawback in the proposed system because when enthalpy of the feed increases, duty of condenser extends due to increase in the minimum reflux ratio. Furthermore, precooling the feed stream leads to a decrease in condenser duty and an enhancement in reboiler duty. In feed-splitting technique a proper fraction of the feed should be heated up with the warmer bottom product in order to recover heat from warm stream. Therefore, it is necessary to introduce the cold feed fraction to a higher column tray to keep the minimum reflux ratio low (avoiding an increase in condenser duty) and the hot feed fraction should be sent to a lower tray to recover the heat from the bottom stream. In feed-splitting technique, there is an optimum fraction of the feed that leads to minimum energy demand of the process and it is tried to explore the best feed splitting ratio, in this study.

The literature regarding to feed-splitting is scarce and usually reported for a single columns [5–9]. For example, Babaie and Esfahani [5] considered different arrangements for separation of propane, butane and pentane. They have found that the prefractionator arrangement with heat integration resulted in the greatest decrease in the total annual cost. Soave and Feliu [6] showed that preheating of the feed by the bottom stream can

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result in a considerable energy saving in the mixture of propane and benzene. Soave et al. [7] also studied feed-splitting technique for cryogenic distillation of demethanizer tower and observed 11% reduction in condenser duty. Since, feed-splitting technique is implemented for reactive distillations and multi-component columns [5,8], thus, this method is not limited to the ordinary columns. In the present research, to extend the use of feed-splitting technique for the azeotropic mixtures, the potential benefit of this procedure in terms of energy saving is examined for extractive separation of CO_2–ethane azeotropic process.

It needs to mention that removal of CO_2 from natural gas is currently a global issue, apart from meeting the customer's contract specifications and for successful liquefaction process [10]. Unfortunately, existence of the minimum boiling point of CO_2–ethane azeotrope in the natural gas processes incurs some problems in separation and purification of the relevant products. High concentrations of carbon dioxide in natural gas occur when carbon dioxide is used for enhanced oil recovery. The separation of CO_2 from the hydrocarbons in the natural gas is complicated due to the existence of an azeotrope between ethane (C_2) and CO_2 at the cryogenic temperatures required for distillation. Accordingly, Lastari et al. [11] recently proposed the low temperature distillation process, which separates CO_2 from ethane in a series of distillation columns using an extractive component of natural gas liquid (NGL, a mixture of propane and heavier hydrocarbons) as typically shown in Fig. 1. Their proposed process, which typically includes two serial distillation columns, generates high pressure CO_2, pure ethane and an amount of NGL. The main disadvantage of Lastari et al. [11] separation process lies in its high capital investment and external energy input required to fulfill the desired purification. In addition, this process is different from conventional extractive distillation columns. Because in conventional extractive columns a third component is added to the system and solvent losses in the product streams requires a make-up stream. However, in the present study, the solvent is a mixture of C_3 and heavier components in which the solvent stream is quite similar to the light key (ethane) and these distinct features of the process leads to some convergence problems. In order to address these issues, we previously reported the reactive absorption for this azeotropic mixture [12]. Due to lack of any published work in feed-splitting strategy for extractive process, the present study investigates two different arrangements for feed-splitting of extractive separation of the azeotrope mixture of CO_2–ethane, using steady state process software of Hysys. Moreover, the optimum fraction of the preheated feed through feed-splitting is also explored and determined to see if any benefit can be procured using sensitivity analysis and the corresponding simulations.

2. Extractive process

2.1. Thermodynamic analysis of extractive column

It is worth to note that the NGL stream, which contains many components (including C_3 and heavier components), is used as an extraction agent for taking CO_2 down to the column, in the present study. Therefore, only to perform a thermodynamic analysis, a system containing CO_2/ethane and n-pentane (that represents NGL as an agent of extraction) is considered in this research. The XY and phase envelope of the system are illustrated in Fig. 2. From Fig. 2, though the relative volatility of CO_2/ethane azeotrope does not significantly change with pressure, the phase envelopes drastically change with addition of n-pentane (see Fig. 2a and b). Furthermore, addition of n-pentane decreases the CO_2 freezing temperature to −75.9 °C that prevents formation of solid CO_2, when pentane mole fraction is equal to 0.6. Fig. 2c also shows that addition of n-pentane (that represents NGL) leads to a higher relative volatility of the CO_2/ethane mixture, and thereby breaking the azeotrope. The

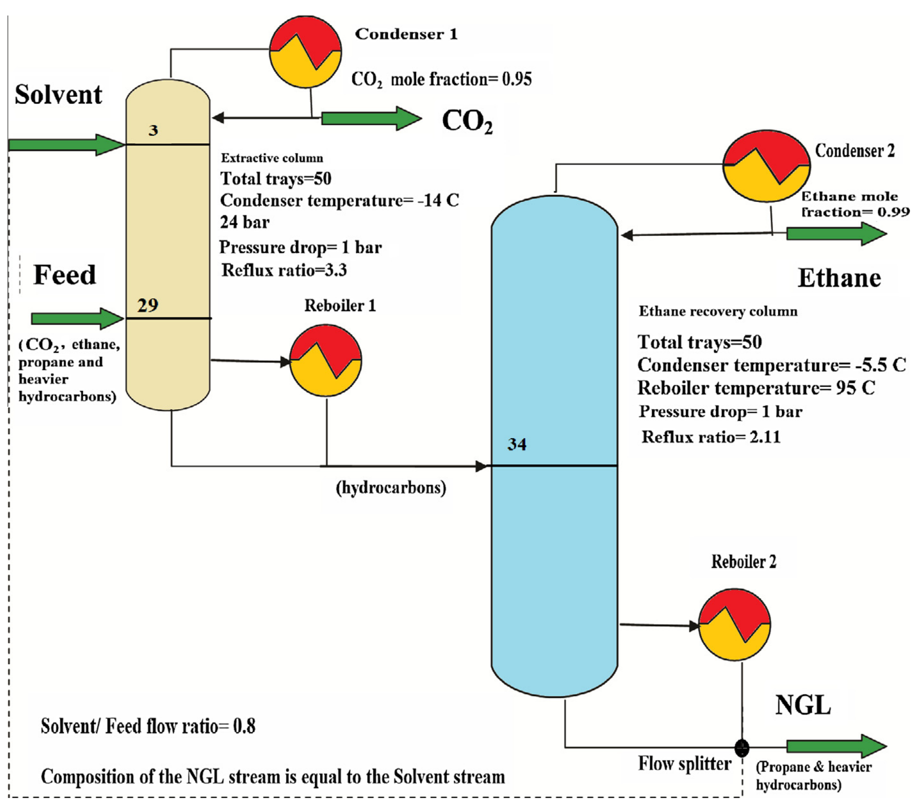

Fig. 1. The diagrams of extractive distillation column.