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Design, optimization and controllability of an alternative process based on extractive distillation for an ethane–carbon dioxide mixture

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A B S T R A C T

Alternative configurations based on cryogenic extractive distillation were proposed and simulated by using Aspen Plus 7.0® coupled to a multi-objective stochastic optimization procedure (differential evolution, DE). The evaluation of the performances of the proposed configurations was focused on the ethane–carbon dioxide azeotrope separation considering different liquefied hydrocarbon fractions as entrainers. The design alternatives were compared to the conventional chemical absorption system.

The proposed sequences were simultaneously Pareto optimized by minimizing the total annual cost (TAC) and maximizing the acid gas removal. Complementary studies regarding the theoretical control properties, the thermodynamic efficiency and the greenhouse gases generation were conducted for several representative operating conditions obtained from the Pareto optimized fronts. The proposed cryogenic extractive distillation sequences realized the higher carbon dioxide removal together with the lower TAC compared to the conventional chemical absorption system.

1. Introduction

According to the BP Outlook [1] and due to the great abundance of the natural gas reservoirs, this fossil fuel will represent the 25% of the energy sources in 2030. It is clear that the optimization of the natural gas treatment process will be fundamental to use efficiently this energy source.

The whole natural gas treatment can be summarized in four steps: acid removal, dehydration, heavy component removal and liquefaction [2]. The gas sweetening is a separation process aimed to remove acid gases, like carbon dioxide and hydrogen sulfide, from the natural gas. The separation of these gases is essential to avoid some operational and safety drawbacks in the natural gas treatment as the reduction on the heat capacity of the gas, the solidification of CO_2 on the next cryogenic steps, the corrosive properties (powered by the presence of water), the formation of by-products, the toxicity, etc.

The intensification of the sweetening section of the process has been studied by different researchers [3,4]. Moreover, the carbon dioxide removal has an extensive interest in other application fields related to the natural gas employment, like the power generation plants [5,6]. In addition to this, another relevant scheme for carbon dioxide separation, namely EOR (enhanced oil recovery), is used. In EOR, the carbon dioxide is utilized to extract the oil from the underground [7,8].

The carbon dioxide removal, from natural gas or other sources, is a long studied topic and among all the alternatives proposed, the absorption using aqueous solution of alcohol–amines is for sure the most widely used process. This configuration is reported in Fig. 1.

Fig. 2 shows a carbon dioxide separation flowsheet utilizing a cryogenic extractive distillation column where some of the natural gas liquid (NGL) is recycled as an entrainer.

Compare to the previous process, this alternative has some advantages:

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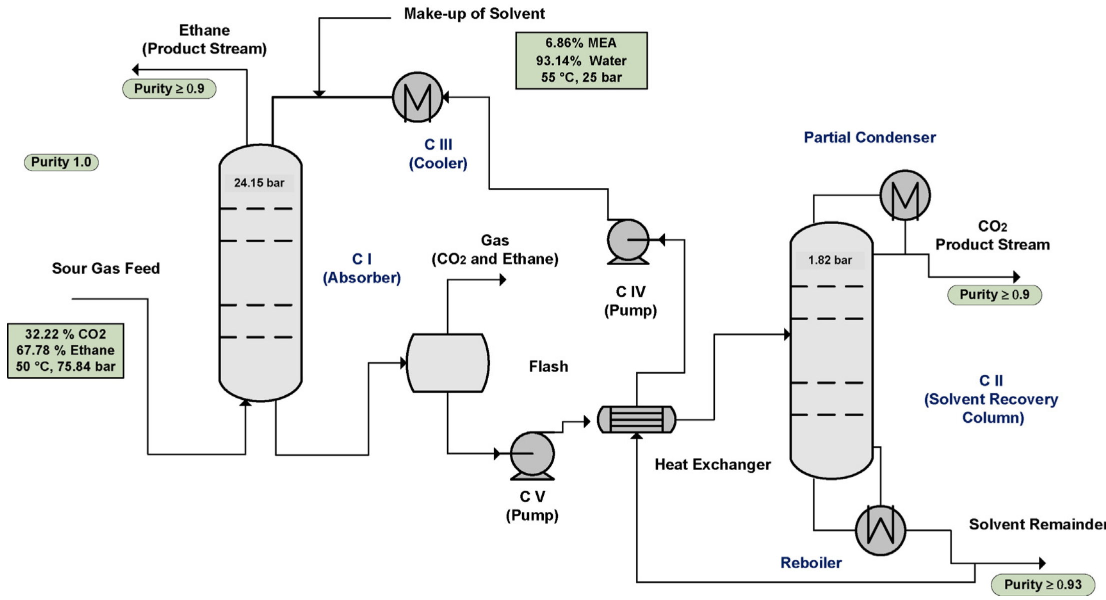

Fig. 1. Conventional chemical absorption system (CCAS), molar basis.

- the entrainer can be obtained from the same facility (as a by-product);
- it is effective for high carbon dioxide concentration feedstock;
- the entrainer can work as a selective sweetener for CO_2;
- it is not necessary a second dehydration step because the solvent used does not contain any water; and
- the non-corrosive behavior of the entrainer makes not necessary to use steel stainless.

On the other hand, the main disadvantages for the cryogenic process are related to the low removal efficiency when the feed contains a high H_2S concentration and the necessity of a cryogenic refrigeration cycle.

2. The alternative thermally coupled distillation sequence

Distillation is characterized for its low thermodynamic efficiency, and consequently the huge energy requirements. Thus, inside the process design area, the thermally coupling concept has emerged as an efficient alternative to reduce the energy consumption, even in those cases where process integration is not possible.

It was proved that for the separation of three component mixtures, thermally coupled sequences were able to reach 30–50% reduction of the energy consumption compared to the conventional distillation sequences [9–11]. Moreover, as reported by different authors, the dynamic properties of these sequences are equal or even better than the corresponding conventional schemes [12,13].

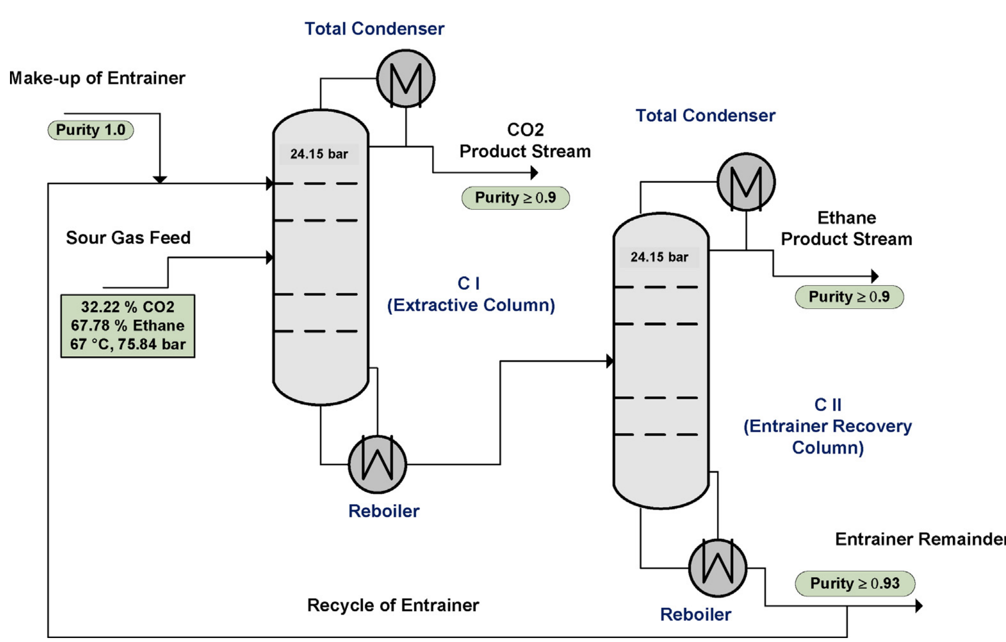

Fig. 2. Conventional cryogenic extractive distillation (CCED) by recycling some liquefied natural gas, molar basis.