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A novel application of reactive absorption to break the CO_2–ethane azeotrope with low energy requirement

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ABSTRACT

Azeotropic separation of ethane and CO_2 using reactive absorption (RA) is studied by Hysys process software. A new configuration of a RA process is proposed using diethanolamine (DEA) to break the azeotrope. Impacts of amine flow rate, amine inlet temperature and feed–inlet location are investigated to achieve an optimum condition of the process in terms of energy demand. The simulation results show that optimum values of amine flow rate, amine temperature and feed–inlet location are 1900 mole/s, 30 °C and 20th stage, respectively. It is found that the process including RA leads to a significant reduction in operating costs, compared to the conventional extractive process.

1. Introduction

1.1. Distillation technology

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. Distillation is therefore the process most targeted when the issue of energy consumption is addressed [2,3]. The base of this process is the difference in volatility of the components which should be separated. The distillation processes design in industrial practice is still conducted by heuristic simulations that require a detailed specification of design parameters [4]. Rising energy prices and stronger requirements on pollution prevention impose a need to continuously update processing conditions, design options and control policies of columns [5]. In order to address energy requirement, several distillation techniques such as simple distillation, partial distillation, flash distillation (equilibrium distillation), rectification, azeotropic distillation, solvent-extraction distillation, and reactive separation processes (RSP) are previously studied [6–8]. Among them, RSP has become an interesting alternative for some conventional processes [9]. The most important examples of RSP are reactive distillation (RD) and reactive absorption (RA) [10].

In RD, reaction and distillation take place within the same zone of a distillation column. Reactants are converted to products with simultaneous separation of the products and recycle of unused reactants. This simultaneous reaction and separation allows crossing of azeotropic concentrations and distillation boundaries, hence facilitating product purification. The equilibrium yield can be significantly increased far beyond equilibrium limitations by continuous product removal from the reaction mixture [11–16]. This process also brings important advantages such as reduction in energy, solvent consumption, the number of equipment unit and avoidance of hot spots by simultaneous liquid evaporation [13]. These advantages lead to the reduction in capital and operating costs. However, the application of RD is somewhat limited by constraints, like, e.g. common operation range (temperature and pressure) for distillation and reaction and difficulties in providing proper residence time characteristics [12]. Similarly, in RA reactions occur simultaneously with the component transport and absorptive separation [17–20]. These processes are predominantly used for the production of basic chemicals, e.g. sulfuric or nitric acids and the removal of components from gas and liquid streams [20–28]. This can be either the cleanup of process gas streams or the removal of toxic or harmful substances in flue gases and liquids [29–33]. Absorbers or scrubbers where RA is performed are often considered as gas/liquid reactors. However, if more attention is paid to the mass transport, these apparatuses are rather treated as absorption units. As both RD and RA occur in multiphase fluid systems and involve gas/vapor and liquid phases, with an important role of the interfacial transport phenomena, they have much in common. For this reason, the

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modeling methods for these both operations are largely based on the same framework, especially regarding the models of trays or packing sections. On the other hand, RD and RA have a number of specific features, which should be considered with care and modeled by different approaches such as different process configurations [34,35]. Since RA offers significant benefits over RD, such as: reduced capital investment and operating costs due to the absence of the reboiler and condenser, higher conversion and selectivity as no products are recycled in the form of reflux or boil-up vapors, as well as no occurrence of thermal degradation of the products due to a lower temperature profile in the column; the role of RA as a core environmental protection process has grown up significantly, and nowadays, this technology has become an interesting alternative for some conventional [36]. Though, there are a large number of research publications in the subject of RA process [20–33], it has received limited attention attributed to the complexity of the underlying phenomena (coupled phase equilibrium, mass and heat transfer and chemical reaction phenomena) taking place in a single unit. This means that it is qualitatively more complex than similar binary processes and special consideration should be given to design of it.

It is well known that carbon dioxide (CO_2) plays a dominating role in the greenhouse effect that CO_2 is representing about 80% of greenhouse gases [37,38]. The rise of CO_2 concentration in the atmosphere, whose origin is mainly anthropogenic, is mostly due to the combustion of hydrocarbons [39–43]. In order to reduce greenhouse gas emissions and fighting the global climate change, it is the need for low energy-consumption, and efficient technologies for the capture and removal of CO_2 from gas mixtures such as post-combustion capture, pre-combustion capture, oxy-combustion or different newly developed technologies capable of ameliorating the process parameters, e.g. chemical looping, polymeric membranes, enzymatic systems [5,44–49]. Global climate change leads to high interest in technologies for CO_2 capture and storage in which CO_2 geological capture is one of the potential solutions to reduce greenhouse gas emissions. The absorption of CO_2 into reactive chemical solvents (aqueous amine solutions) is one of the most promising technologies for capturing CO_2 due to its maturity, cost effectiveness, and capability of handling large amounts of exhaust stream [47–52]. Moreover, RA is the only technology that can be implemented quickly on a large scale at existing plants for that purpose because it does not require significant changes in the equipment configuration.

1.2. Case study

Based on literature survey, removal of CO_2 from natural gas is currently a global issue, apart from meeting the customer's

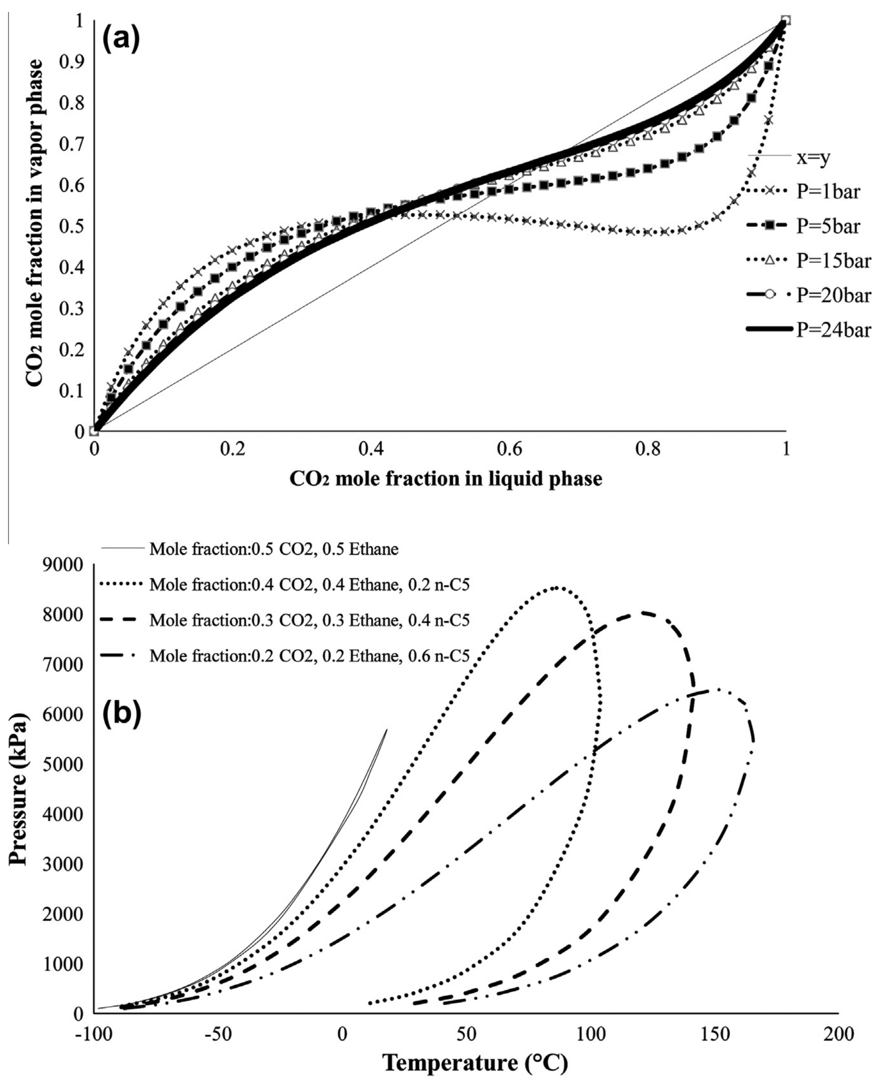

Fig. 1. Thermodynamic analysis of CO_2–ethane azeotropic process in terms of (a) XY diagram and (b) phase envelope diagram.