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Gas-liquid membrane contactors for carbon dioxide separation: A review

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ABSTRACT

Membrane gas–liquid contactors have been developed to reduce the capital cost and energy consumption of conventional CO_2 absorption and stripping columns. As a hybrid technology of membrane separation and amine absorption, these units can improve the gas absorption process by generating 400–1500% greater mass transfer area per unit volume leading to smaller equipment sizes. Regeneration of CO_2 can occur within a membrane contactor below the boiling point of the solvent, leading to lower energy consumption. Over recent years, a vast array of polymeric and ceramic materials have been considered for membrane gas–liquid contactors and an array of solvents have been used including amines, potassium carbonate, ammonia and amino acids. The major technical challenge with membrane contactors is the wetting of the membrane pores with solvent, which reduces the mass transfer coefficient. However, other factors such as the choice of solvent, the placement of the solvent on the shell or lumen side and the operational temperature are also critical to success. This review describes the recent progress in membrane gas–liquid contactor technology for CO_2 separation in terms of the materials, solvents, modules and processes and provides direction on where research can best be directed in the future to enhance the feasibility of the technology's industrial application.

1. Introduction

Carbon dioxide (CO_2) is a major focus of separations research as it is a major greenhouse gas and an impurity in natural gas. Raw natural gas can contain a considerable amount of CO_2 that must be removed because it can cause corrosion to pipelines and equipment, reduce the heating value of the gas and prevent effective natural gas liquefaction [1]. Traditionally, CO_2 absorption and subsequent desorption into an amine solvent has been used for this purpose, due to its high reactivity and selectivity. Packed columns are widely used for this operation in refineries, petrochemical plants, natural gas processing and chemical processes using standardised and proven designs (Fig. 1(a)). More recently, CO_2 emissions generated by fossil fuel combustion from power plants have become a global issue for climate change [2] and in this situation the amine process is also efficient and effective even though the CO_2 is present at low partial pressure.

CO_2 separation using membrane technology was first developed for natural gas purification as an alternative to amine solvents in the 1980 s and has since expanded its market share. Gas separation membranes can selectively permeate target gas molecules due to properties such as the kinetic diameter or chemical interactions between the gas and the material [3-5]. Membrane-based separation is efficient because it does not involve a phase change and this leads to low energy consumption, but its performance is maximised only when the input gas stream has a high partial pressure [6]. At the low partial pressures available in the flue gas from power plants, membrane processes that use commercially available membranes are unable to achieve the necessary purity and selectivity for CO_2, illustrating the need for advanced membranes.

A membrane gas–liquid contactor is a hybrid technique that combines membrane separation and solvent absorption. The membrane separates the gas and liquid phases at the interface, providing the mass transfer contact area for CO_2 absorption and desorption [7] (see Fig. 1 (b)). Ideally, the membrane in a CO_2 gas–liquid contactor only permeates CO_2 molecules while rejecting transport of solvent or other gas molecules such as nitrogen (N_2) in flue gas or methane (CH_4) in natural gas. Although all feed components transport through the membrane pores, only CO_2 can diffuse into the solvent due to its high CO_2 selectivity. Compared to a conventional packed column amine process, a membrane contactor provides much greater mass transfer area per unit volume (1500–3000 m^2/m^3) compared to a column contactor (100–800 m^2/m^3) [8]. This is advantageous for offshore natural gas sweetening and brownfield carbon capture processes where space can be limited.

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