Gas Transport Model for Hydroxide-Ceramic Dual-Phase Membrane

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Abstract

Membrane-based technologies offer an inherently energy-efficient solution to the carbon sequestration problem, as they do not involve a phase change, unlike the amine absorption approaches. However, the development of this technology has been hampered by the lack of membranes that sufficiently combine high CO_2 selectivity with high flux. Among many membrane materials, carbonate-ceramic dual-phase membranes have been considered as a solution to efficient CO_2 capture from flue gas because of their high CO_2 selectivity/permeance at high temperature (> 650 ºC). However, to achieve acceptable CO_2 flux, the carbonate-based dual-phase membranes must operate at temperatures above 650 °C, which is higher than the flue gas temperature around 350 ºC when it leaves the economizer, and would require burning additional fuel to heat the CO_2 separation system to the operating temperature. A dual-phase membrane based on molten hydroxide is also highly selective towards CO_2 at the intermediate temperature range (300-600 ºC) because CO_2 absorption by alkali hydroxides (e.g. KOH) is reversible in the presence of H_2O due to a phase change near 250 ºC. Indeed, the hydroxide-based membrane shows high CO_2/N_2 selectivity (>1000) and high CO_2 permeability (8×10^{-11} mol m^{-1} s^{-1} Pa^{-1}).

In this work, we will present a comprehensive gas transport model using Nernst-Planck equation to improve understanding on the CO_2 separation properties of the hydroxide-ceramic dual-phase membrane. The CO_2 separation performance of the dual phase membrane strongly depends on the conductivity of the molten phase. However, typical gas transport models assuming constant conductivity of the molten phase across the membrane do not reflect the actual gas permeation mechanism. Our gas transport model based on Nernst-Planck equation can better simulate the variation of the conductivity and ion concentration across the dual phase membrane. This gas transport model has been well-validated by the experimental data. Results showed that the CO_2 flux across the membrane can be enhanced by optimizing the hydroxide ion concentration in the molten phase. The membrane containing 36.4 % of hydroxide in molten phase demonstrates an order of magnitude higher CO_2 permeability than the other carbonate-based dual phase membranes reported hitherto.