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Synthesis and performance evaluation of nanocomposite ceramic-sodalite membranes for pre-combustion CO2 capture

Oloye, Olawale

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ABSTRACT

Global climate change and other environmental disasters have been attributed to continuous anthropogenic carbon dioxide (CO_2) emission into the atmosphere. Today, researchers are constantly seeking measures to reduce anthropogenic CO_2 emission. Traditionally, absorption technology with use of monoethanolamine (MEA) is used for separating / capturing of anthropogenic CO_2. However, the use of MEA is associated with numerous shortcomings, including inefficient energy usage, high operating and capital cost, amine degradation, solvent loss and excessive equipment corrosion. Alternatively, zeolite based membrane systems are promising technique that prove handy and useful than the traditional processes (absorption with monoethanolamine). However, zeolitic membranes with zeolite coating on the supports (i.e. thin-film supported zeolite membranes) are susceptible to abrasion and thermal shock at elevated temperatures due to temperature mismatch between the supports and the membranes, making them to lose selectivity at early stages. On the contrary, nanocomposite architecture membranes, synthesized via pore-plugging hydrothermal route, are more thermally stable and membrane defects are controlled. Nanocomposite zeolite (sodalite) membranes have been proposed for gas separations, most importantly in the separation of H_2/CO_2, a major component in pre-combustion carbon capture. In addition, sodalite, a porous crystalline zeolite made up of cubic array of β-cages as primary building block having cage aperture in the range of 0.26 and 0.29 nm, is a potential candidate for the separation/purification of light molecules such as hydrogen which has a cage aperture of 0.27 nm under certain process conditions.

In this work, nanocomposite architecture hydroxy sodalite membrane with sodalite crystals embedded within α-alumina tubes were successfully synthesized using the pore-plugging hydrothermal synthesis technique and characterized using techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD). The morphology of the synthesized membranes shows that sodalite crystals were indeed grown within the porous structures of the support. Furthermore, Basic Desorption Quality Test (BDQT) and gas separation measurement were conducted to evaluate the quality of the as-synthesized membrane in industrial gas separation applications. The effects of operating variables such as pressure at 1.1 bar, 2.0 bar and 3.0 bar. Also, the effects of temperature were conducted on the nanocomposite membrane at 373 K, 423 K and 473 K. Finally, the gases permeation results were fitted with the well-known Maxwell-Stefan model.

Results indicated that, the nanocomposite sodalite / ceramic membrane is a potential candidate for removal of H_2 from H_2/CO_2 mixture. The gas permeation measurement from the one-stage nanocomposite membrane shows that the membrane displayed H_2 and CO_2 permeance of 3.9 x 10^{-7} $mols^{-1}m^{-2}Pa^{-1}$ and 8.4 x 10^{-8} $mols^{-1}m^{-2}Pa^{-1}$, respectively. However, the morphology of two-stage nanocomposite membrane shows that the support was more plugged with sodalite crystals and the permeance of H_2 and CO_2 were 7.4 x 10^{-8} $mol.s^{-1}.m^{-2}.Pa^{-1}$ and 1.1 x 10^{-8} $mol.s^{-1}.m^{-2}.Pa^{-1}$, respectively. Consequently, the H_2/CO_2 ideal selectivity for the one-stage nanocomposite membrane improved from 4.6 to 6.5 in the two-stage nanocomposite membrane.

In conclusion, the two-stage synthesized membrane shows better improvement. The porous support was well plugged and separation performance was evaluated. However, occluded organic matters present in the cages of hydroxy sodalite could have adverse effect on the gas permeation performance of the membrane. It is expected that an organic-free sodalite supported membrane (such as silica sodalite supported membrane) could out-perform the hydroxy sodalite supported membrane reported in this work in term of membrane flux because there will be enough pore space for gas permeation.