Chapter 7

Recommendations for Future Work

7.1. Silica Composite Membranes

In the present work, silica composite membranes for hydrogen separation were successfully prepared by chemical vapor deposition. A defect-free γ-alumina multilayer was also obtained by placing boehmite sols of different particle sizes on macroporous alumina support. The application of silica composite membranes for hydrogen separation for application in membrane reactors for steam reforming can be extended broadly to cover other separations, one example, is the purification of natural gas. All natural gas requires extensive treatment due to strict pipeline specifications (Table 7.1) [1]. Removal of CO_2 before it can be passed to pipelines is extremely important due to the loss of the energy content of the natural gas and because of its acidic and corrosive nature of $CO_2$when mixed with water, which is also present in natural gas.

Amine absorption plants are commonly used for CO_2 separation but in the 1980s with improvements in membrane technology, CO_2 selective cellulose acetate membrane plants joined the industry. Currently, these membranes have a CO_2/CH_4 selectivity of 15 under normal operating conditions and are starting to be replaced by polyimide and polyaramide membranes which have selectivities of 20-25 [1]. At high CO_2 pressures, these membranes are vulnerable to the plasticization effect of CO_2 on polymers and may loose their separation ability. On the other hand, inorganic membranes are promising with their superior thermal, mechanical and chemical stability and are reported as candidates for CO_2/CH_4 separation in the literature. Kusakabe et. al. [2] demonstrated a CO_2/CH_4 separation factor of 20 at 303 K with a FAU type zeolite membrane. Lovallo et. al. [3] showed a CO_2/CH_4 separation factor of 16 at 393 K and 5.7 at 453 K with a MFI type zeolite membrane. The ideal selectivities obtained at room temperature for ZSM-5, Y-type and X-type membranes were 2.4-5.5, 10 and 28 respectively [4]. In contrast, Cui et. al. [5] obtained a CO_2/CH_4 selectivity of 400 and a CO_2 permeance of $4.6x10^{-8}$ mol/m^2s Pa at 308 K for a transmembrane pressure of 0.1 MPa with a T-type zeolite. Tomita et. al. [6] reported a CO_2/CH_4 selectivity of 220 and a CO_2 permeance of $7x10^{-8}$ mol/m^2s Pa at 301 K for a pressure drop of 0.5 MPa by using DDR type zeolite membranes prepared on porous alumina tubes. Li et. al. [4] prepared SAPO-34 membranes on stainless steel tubular supports and observed a CO_2/CH_4 selectivity of 150 at 253 K for a pressure drop of 3 MPa. The results show that inorganic membranes have promise for the separation of CO_2 form CH_4 in natural gas.

Table 7.1. Composition specifications for natural gas for delivery to the U.S. National Pipeline Grid

Component	Specification
Carbon dioxide	<2%
Water	<120 ppm
Hydrogen sulfide	<4 ppm
	950-1050 BTU/scf
C_{3+} content	Dew point -20 ^{0}C
Total inert gases (N_2, He, etc.)	<4%

7.2. Modeling of membrane reactors

In this study, the one-dimensional and two-dimensional modeling of the packed-bed and the membrane reactor are proposed based on the assumption of isothermal conditions. It was concluded that the prediction of radial profiles in the reactor especially at high pressures was critical for the analysis and design of the membrane reactors. For the precise analysis of the membrane reactors, the estimation of temperature distribution in the axial and radial directions should also be considered as an objective of future study.

A non-isothermal two-dimensional study has been performed for the dehydrogenation of ethylbenzene [7]. The analysis showed a considerably rapid change in the temperature distribution in the reactor because of the reaction being a relatively large endothermic reaction. Another non-isothermal two-dimensional study which examined the dehydrogenation of propane [8] in a membrane reactor indicated that even in a narrow reactor (0.7 cm diameter), some temperature gradients can be observed. These results suggested that radial temperature profiles must be taken into account for analysis of wider reactors. Thus, studies concentrating on reactor radius are called for.

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