Morphological characterization of multilayer hydrophobic ceramic membranes

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Highlights

- Top-layer porosity/tortuosity ratio is characterized
- Permeance is described by Dusty Gas model
- Good modules performances are obtained in Sweeping gas membrane distillation

1. Introduction

Ceramic membranes, operating in membrane distillation mode, are deemed to withstand relatively high operating temperatures when compared to polymeric membranes, since high temperatures promote higher transmembrane fluxes. Hydrophobic membrane contactors are typically proposed for mass transfer operations in which vapor-liquid interfaces are necessary to perform absorption and/or stripping processes or others, avoiding the dispersion of one phase into the other.

The final aim of this study is to test the feasibility of a reaction step followed by a stripping unit, by using a Sweeping Gas Membrane Distillation (SGMD) operation with ceramic membranes, for the regeneration of a lean solvent, in which the operation is to be integrated with an existing absorption step of an industrial process. Since the regeneration should operate at temperatures higher than 100 °C in order to enhance the chemical reaction conversion, hydrophobic ceramic membranes are considered as the most suitable [1].

In this work, the morphological characterization of prototype multilayer membranes is performed in order to investigate the effect of the hydrophobic coating on the top-layer. The study is concluded by tests of modules performances during SGMD using NaCl-water solutions to evaluate the applicability of the prototypes.

2. Materials and methods

Macroporous multilayer TiO_2 membranes were used (prototypes by Fraunhofer Institute for Ceramic Technologies and Systems-IKTS, Germany) in tubular and in capillary types. The membranes' top layers were coated by a combination of fluoroalkylsilanes and a polymer (confidential materials) to provide hydrophobicity (tested by liquid breakthrough measurements with pure water). Coated ceramic samples are 4-layer membranes of pore radius that is progressively decreasing from the bottom to the top-layer (100 nm) where the coating is located. Morphological properties are given by the manufacturer [2], with the exception of the porosity/tortuosity ratio of the top-layer.

Morphological characterization was performed by using gas (nitrogen or air) flux measurements at room temperature, as a function of pressure difference across the membranes, at different values of average pressures. Tests were carried out both on uncoated and coated samples.

Bundles performances were tested in a SGMD pilot, by using NaCl-water solutions. Experiments ran at liquid temperatures from 60 to 110 °C, at different gas pressures, by keeping a sufficient pressure difference across the membrane to avoid pores flooding. The rate of change of NaCl concentration was measured by a conductimeter; data were elaborated to calculate the total transmembrane flux.

3. Results and discussion

The Dusty gas model (DGM) was implemented in the morphological characterization, assuming that permeation across the membrane occurs according to the contributions of Knudsen diffusion and the viscous flow [2], neglecting the slip contribution.

Experimental results of gas permeance are reported in Figure 1. On coupling the DGM and permeation results for the uncoated single channels, it was managed to fit the value of porosity/tortuosity ratio of layer 3. A comparison between the experimental permeances of coated membranes and those of uncoated membranes, showed a negative effect of the coating on the overall membrane permeance. Since the manufacturer certified that the coating has a molecular dimension, the decreasing permeance was ascribed to a sort of pore size reduction caused by the coating procedure. Based on geometrical considerations, the DGM was used to fit the effect of coating and then the porosity/tortuosity ratio of the coated layer 3 was finally calculated.

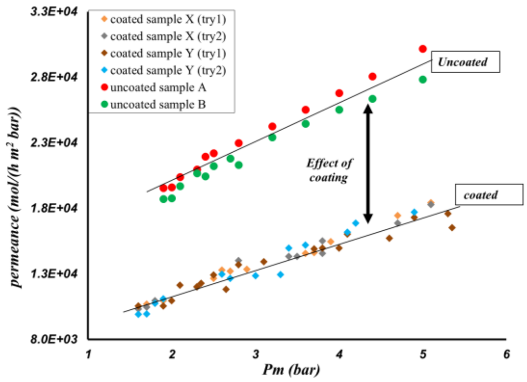

Figure 1. Effect of coating on air permeance at room temperature in 100 nm –top layer single channels. Comparison between permeances of coated and those of uncoated membranes

In case of SGMD modelling, the film theory was adopted to describe mass transfer in the liquid side and in the gas side, as it is usual in NaCl-water application, accounting of molecular diffusion and Knudsen diffusion across the membrane.

The comparison between the experimental fluxes and the predicted values is reported in Figure 2, in which a good agreement can be observed, thus supporting the good quality of the prototype modules in SGMD operations.

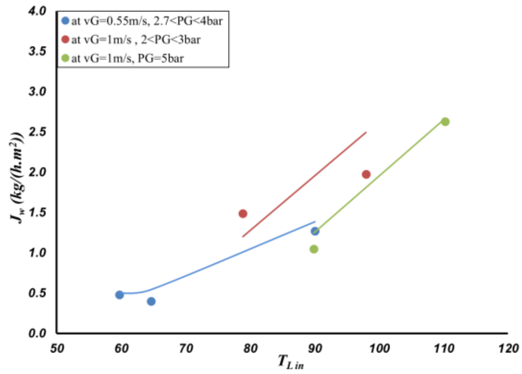

Figure 2. SGMD of (20 g/kg) NaCl-water solutions. Comparison between experimental (data points) and predicted (lines) water fluxes vs. the liquid temperature at various gas velocities and pressures. (0.45 m/s liquid velocity, 25°C inlet gas temperature). Liquid=tube side, gas=shell side; counter-current flow pattern

References

[1] S. Koonaphapdeelert, Z.Wu, K.Li, Carbon dioxide stripping in ceramic hollow fibre membrane contactors,

Chemical Engineering Science 64,1-8, 2009

[2] M.Weyd , H. Richter , P. Puhlf¨urß , I.Voigt , C.Hamelb, A.S.Morgenstern , Transport of binary water–ethanol mixtures through a multilayer hydrophobic zeolite membrane, Journal of Membrane Science 307,239–248, 2008

Keywords
Hydrophobic ceramic membranes, morphological characterization, Dusty Gas Model, sweeping gas membrane distillation