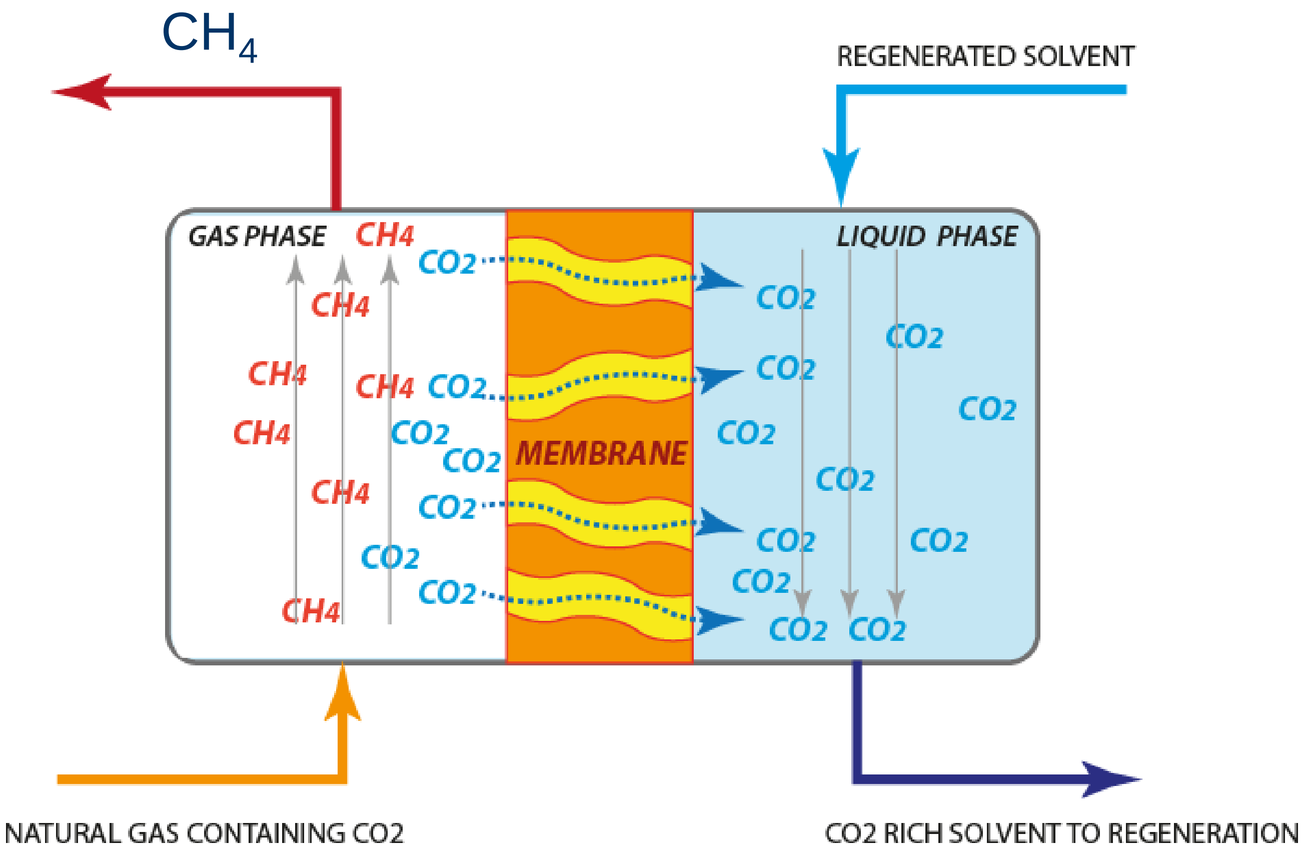
Membrane contactor for CO_2 capture

Taek-Joong Kim
Department of CO_2 Capture Process Technology
Sustainable energy technology Sector
SINTEF Materials and Chemistry

Overview

- What is membrane contactor?
- Advantages
- Mass transfer resistance
- High pressure
- Wetting
- Materials
- Long-term stability
- Actual operation window
- Counter-current
- Microporous
- Concluding remarks

What is membrane contactor?



Basic Concept of Membrane Gas-Liquid Contactor for Natural Gas Sweetening
(the original figure at thegreenasia.com (Advantages of Membrane Gas Absorption Method) posted by Asela De Silva on Feb 21, 2010)

http://www.co2crc.com.au/aboutccs/cap_membranes.html

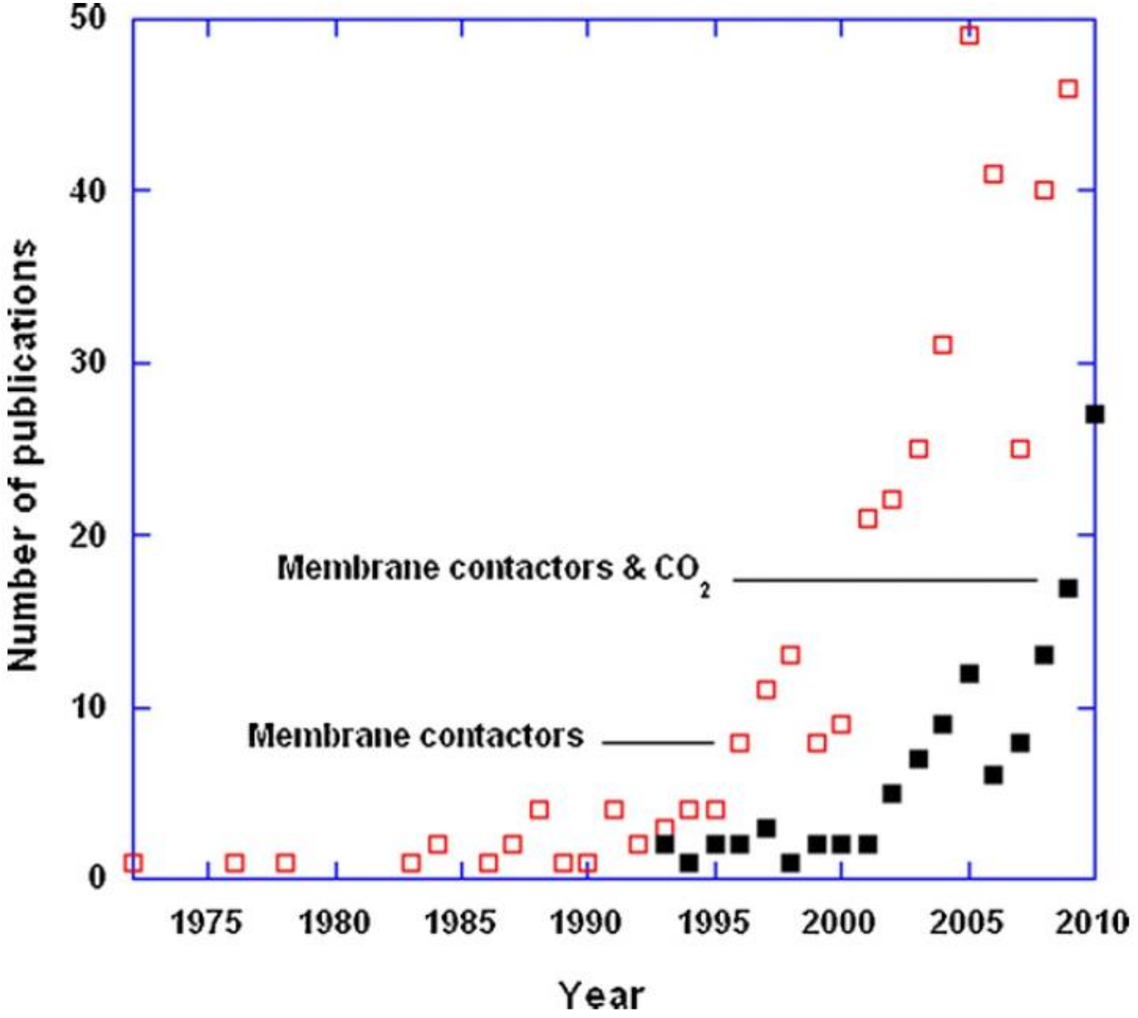


Fig. 1. Evolution of the number of publications per year in scientific journals which include the keywords "membrane contactors" (closed squares) and "membrane contactors + CO_2" (open squares).

ISI Web of Science, December 2011.

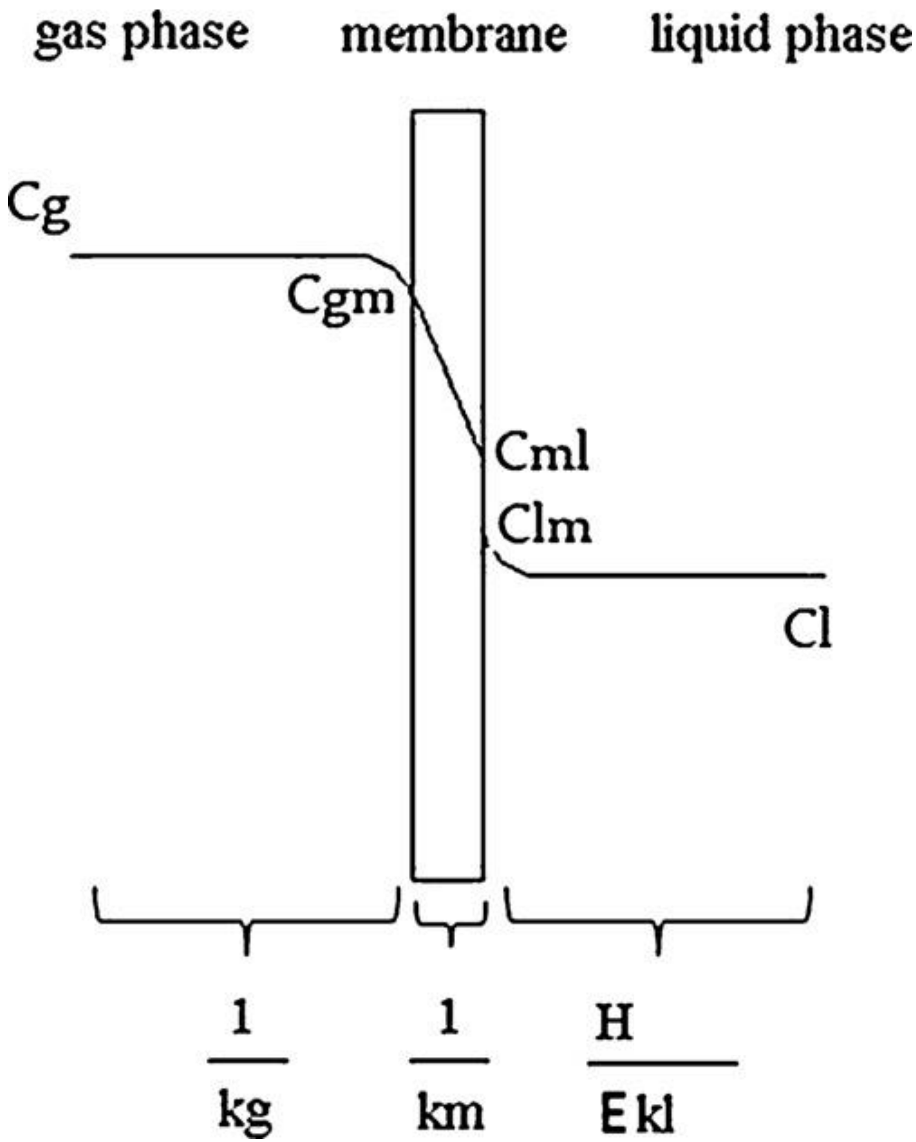
Favre and Svendsen / Journal of Membrane Science 407–408 (2012) 1–7

Advantages of Membrane Contactor

- High surface area per unit contactor volume
- Independent control of gas and liquid flow rates
- Free of entrainment and flooding
- Modularity and easy scale up or down
- Process intensification

Bougie et al. / Chemical Engineering Science 123 (2015) 255–264

Added resistance?



P.T. Nguyen et al. / Journal of Membrane Science 377 (2011) 261– 272

High pressure?

High pressure
High temperature
- Swelling
- Compression
- Wetting

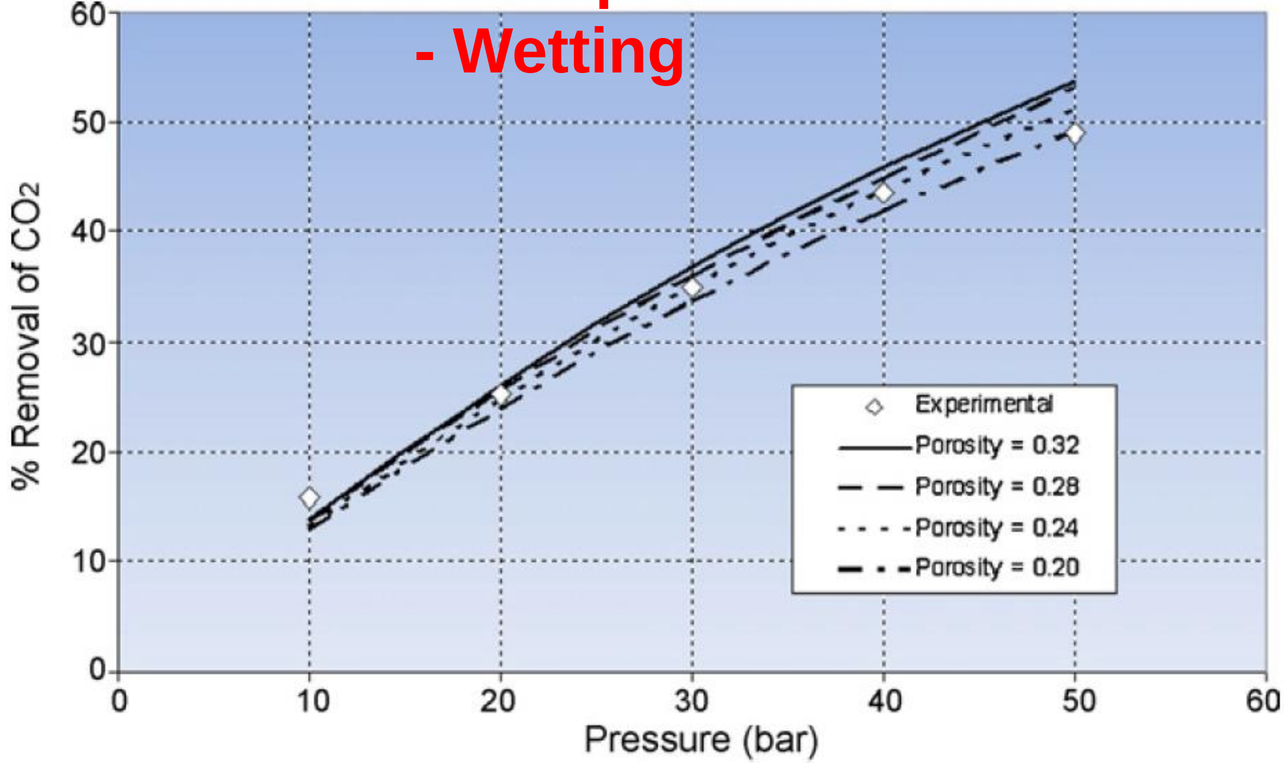


Fig. 6. Effect of porosity on the physical absorption of CO_2 using pseudo-wetting (0.5%), gas flow rate = 800 (ml min^{-1}), liquid flow rate = 100 (ml min^{-1}), tortuosity = 3.

Faiz et al./ Journal of Membrane Science 365 (2010) 232–241

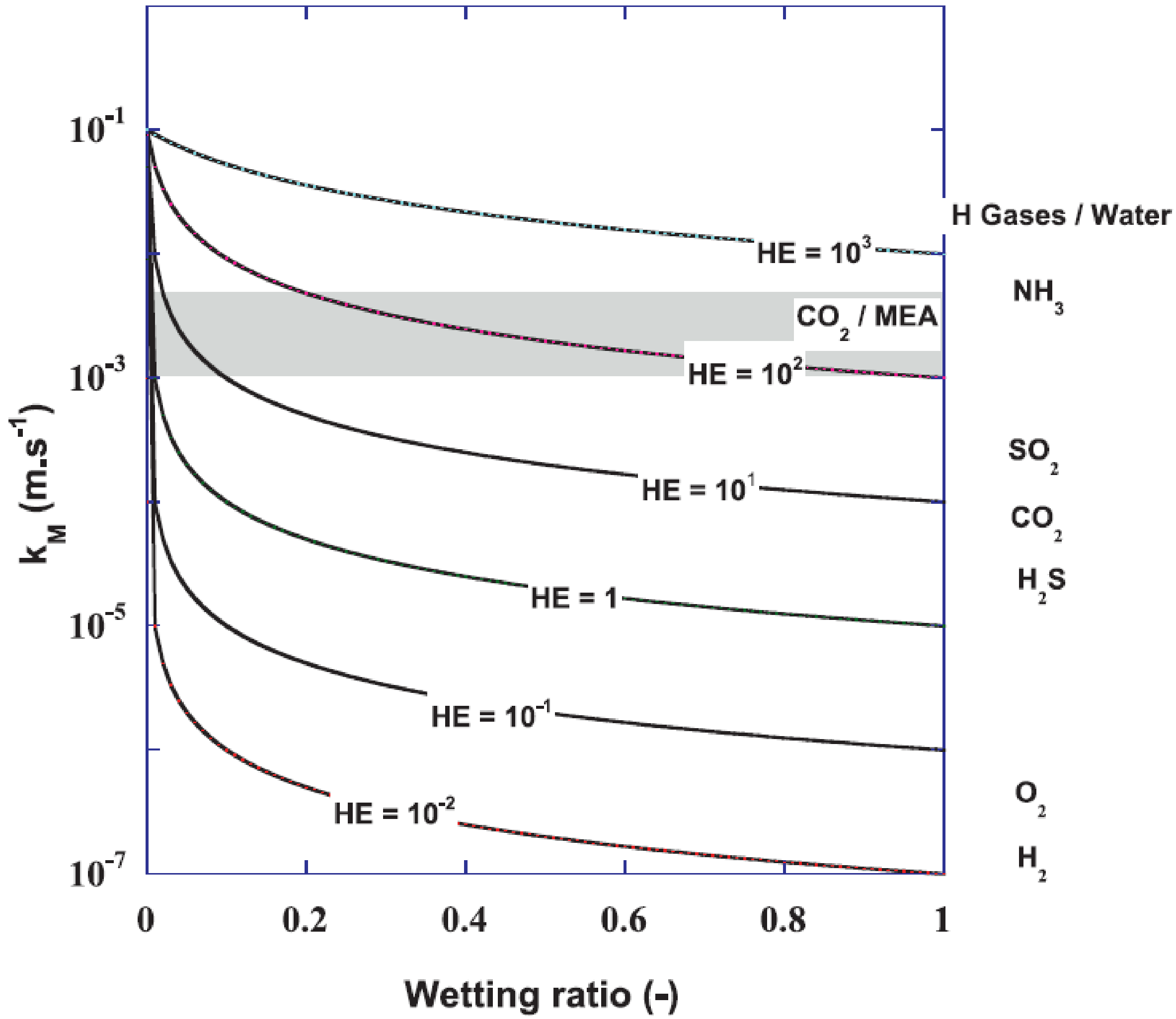
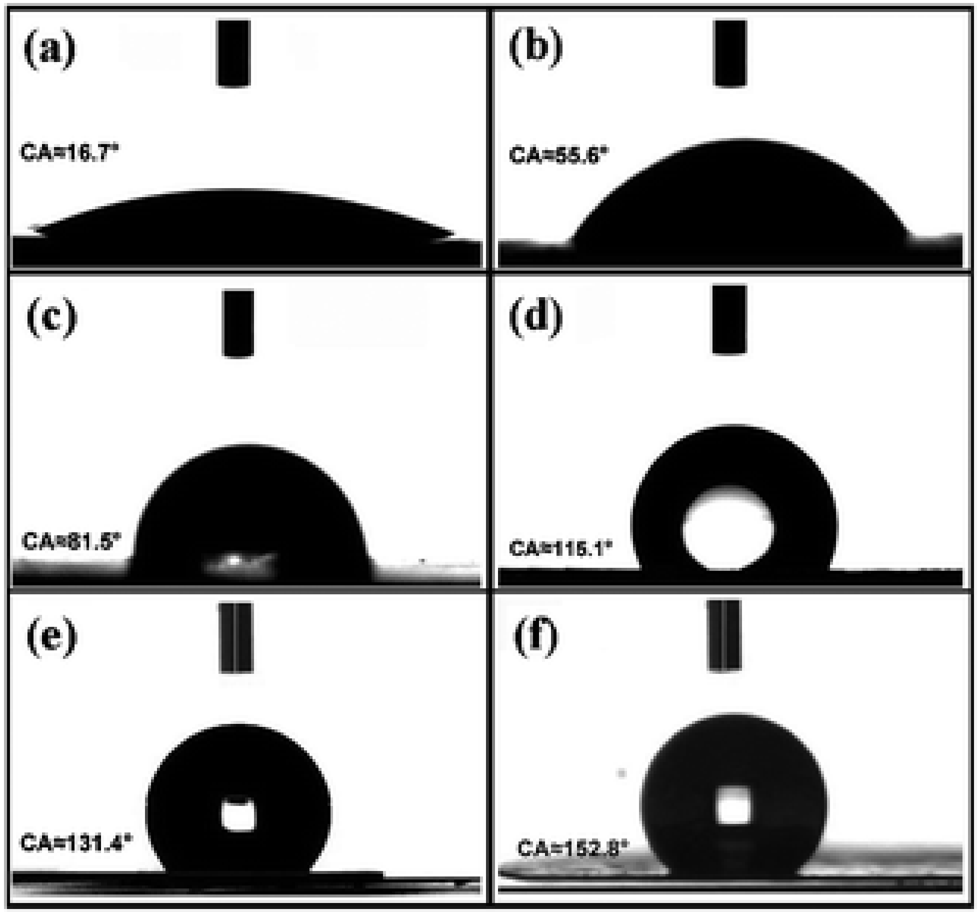


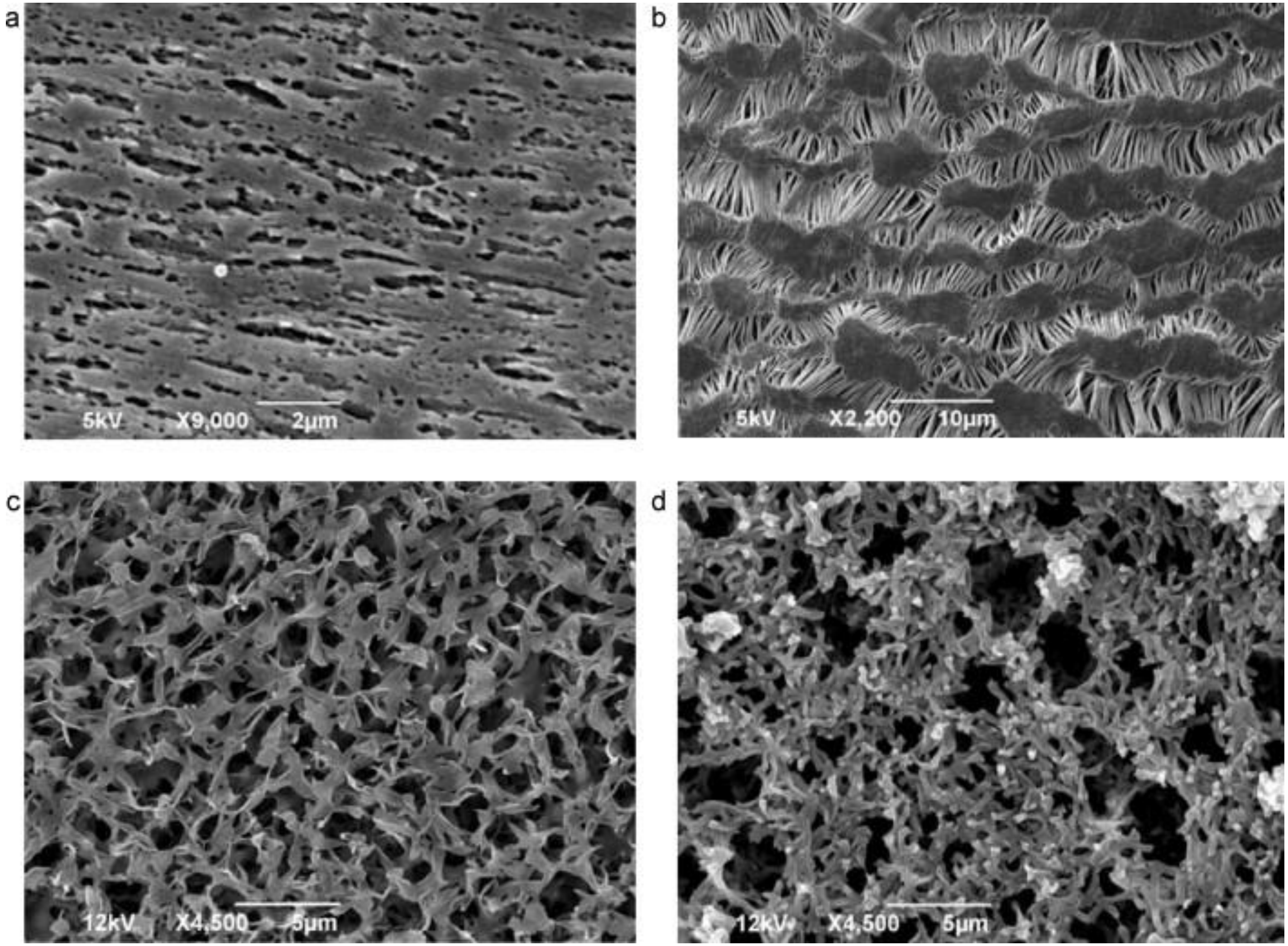
Fig. 4. Influence of wetting on the effective membrane mass transfer coefficient (k_m) based on resistance in series approach. The diffusion coefficients in the gas and liquid phases are assumed to be 10^{-5} and 10^{-9} $m^2\,s^{-1}$, respectively. The different curves correspond to different values of H.E, where H is the gas–liquid Henry coefficient and E the enhancement factor. For CO_2 absorption in MEA, H.E usually ranges between 100 and 300.

Favre and Svendsen / Journal of Membrane Science 407–408 (2012) 1–7



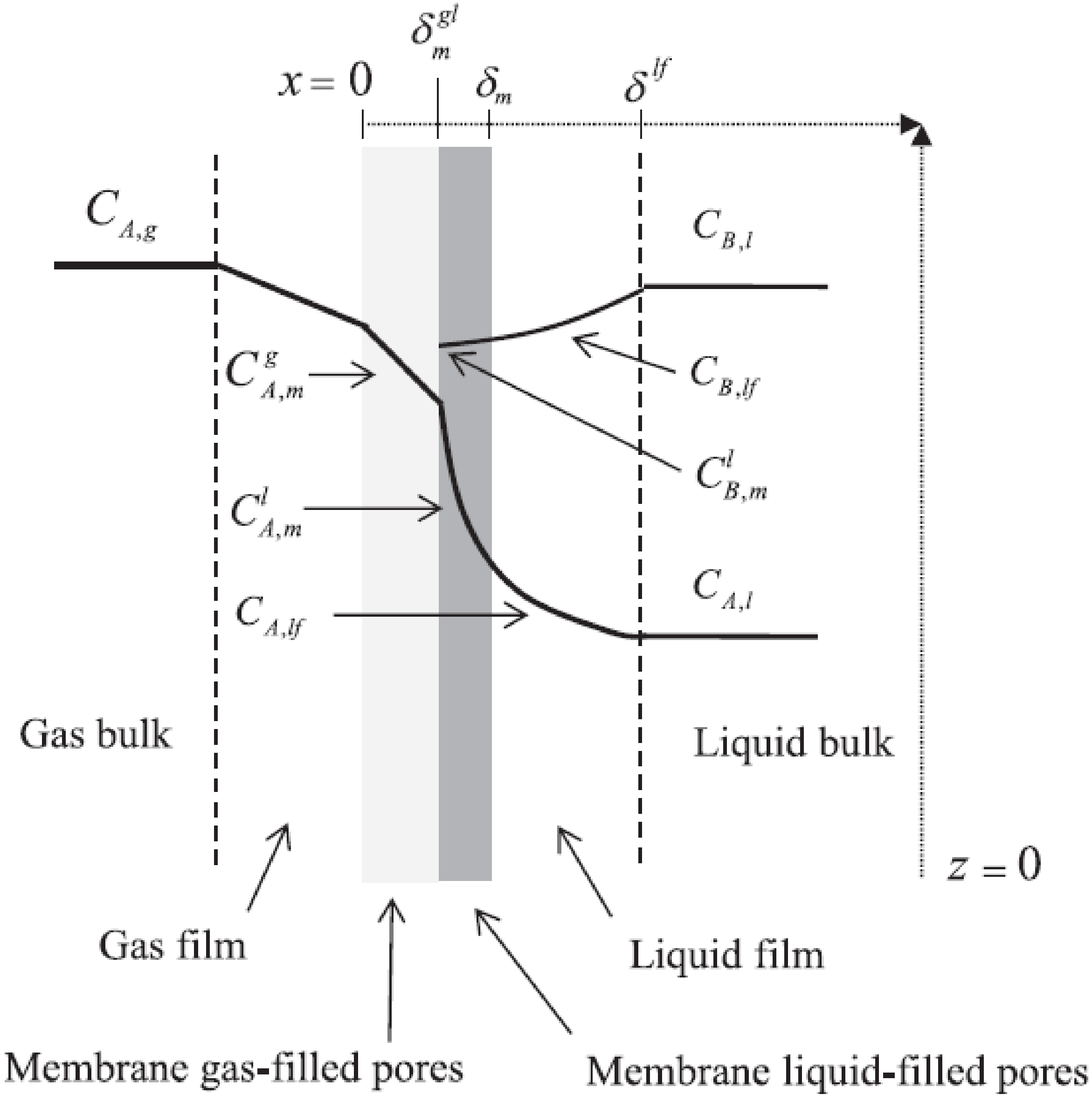
$$\Delta P_c = -\frac{2\gamma_L \cos\theta}{r_p}$$

Tang et al. / J. Mater. Chem., 2006,16, 1741-1745



Porous structures for membrane contactor applications showing the differences in pore size distribution, pore geometry and material structure:
(a) PP, (b) PTFE, (c) PVDF, (d) PES.

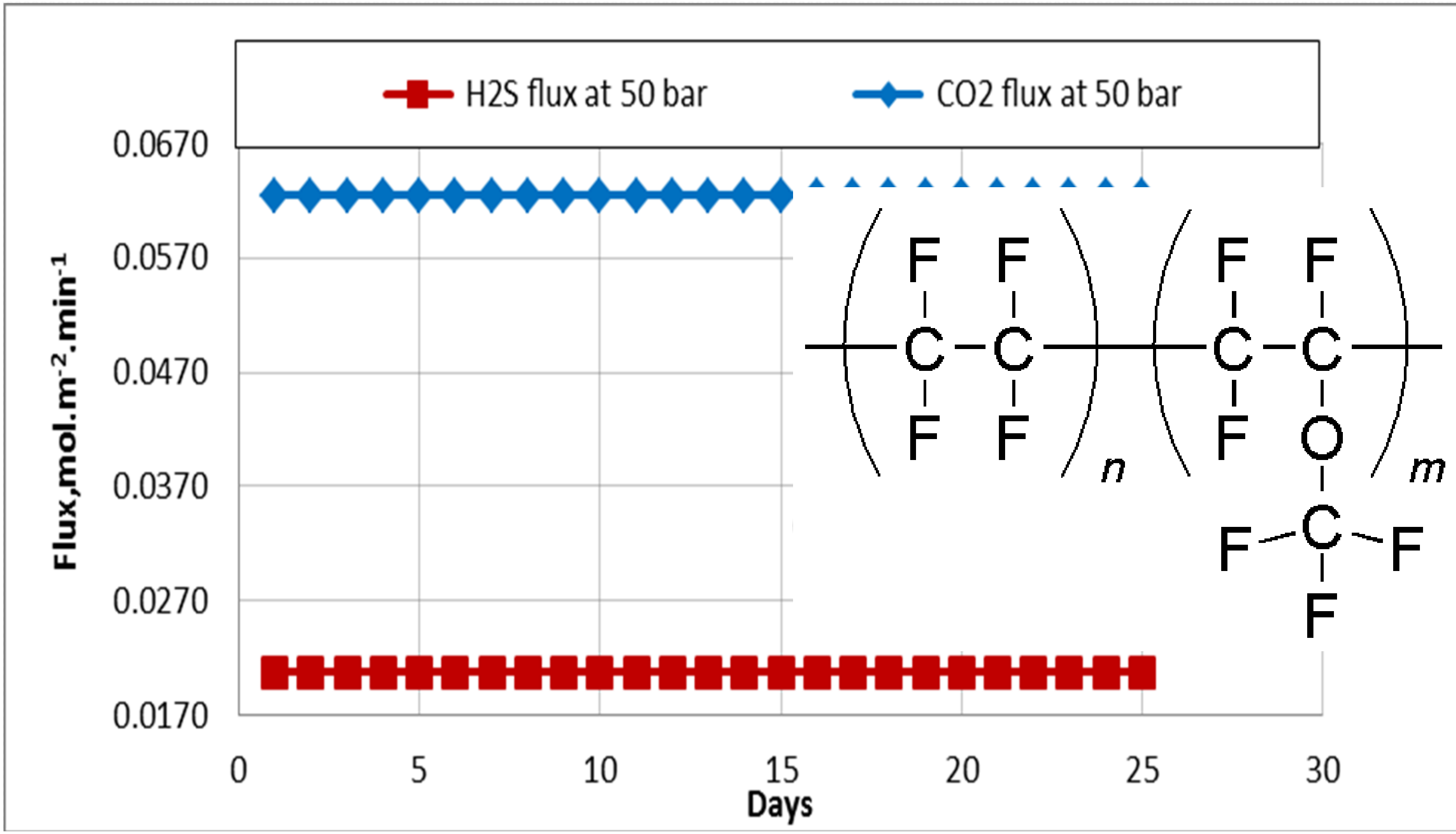
Favre and Svendsen / Journal of Membrane Science 407–408 (2012) 1–7



F. Bougie et al. / Chemical Engineering Science 123 (2015) 255–264

Materials?

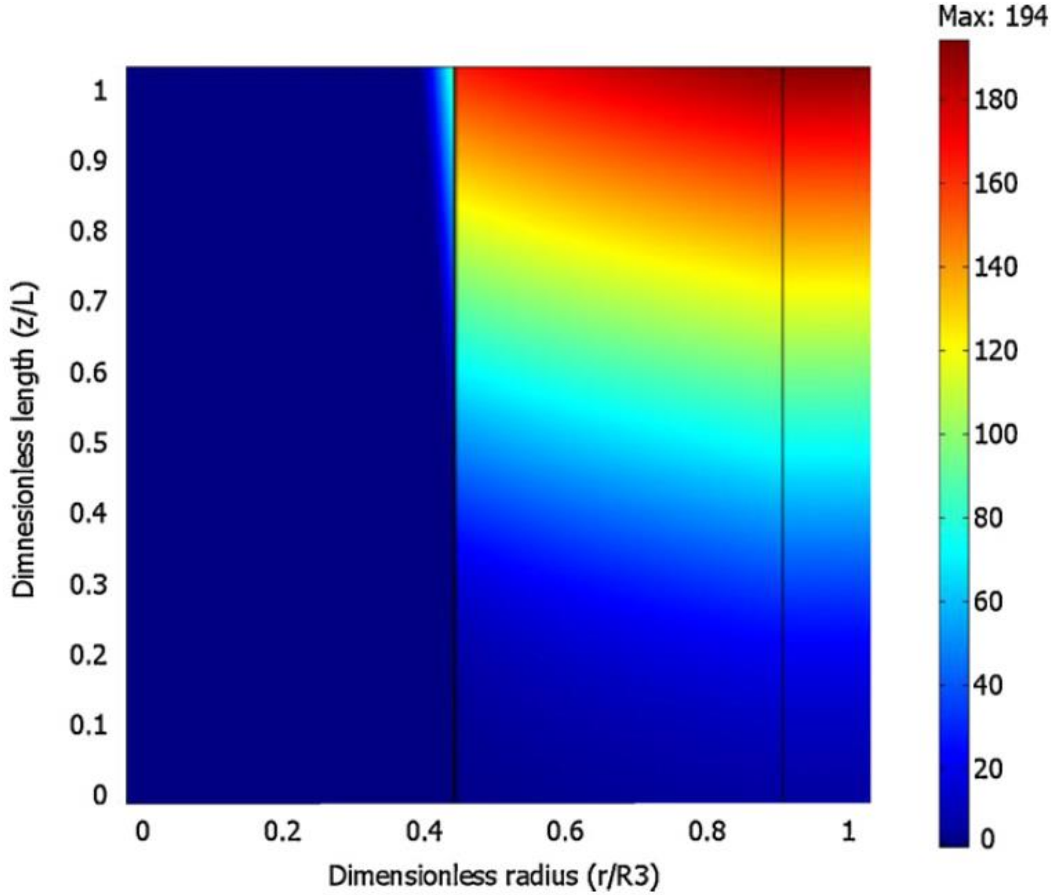
Long-term stability?



i) Feed gas composition: ETHANE 6.9%m, PROPANE 3.6%m, METHANE 81.64%m, CARBON DIOXIDE 4.2%m, HYDROGEN SULFIDE 1.4%m, ISOBUTANE 0.3%m, NITROGEN 1.4% m and NBUTANE 0.56%m).
ii) The solvent composition: 30wt% K2CO3 + 1wt% DEA solution,
iii) Feed gas temperature: 50 oC; Solvent temperature: 100 oC,
vi. Feed gas pressure: 50 bar

Al-Marzouqi et al. / https://www.jccp.or.jp/international/conference/docs/1-2UAEU.pdf

Actual operation window?



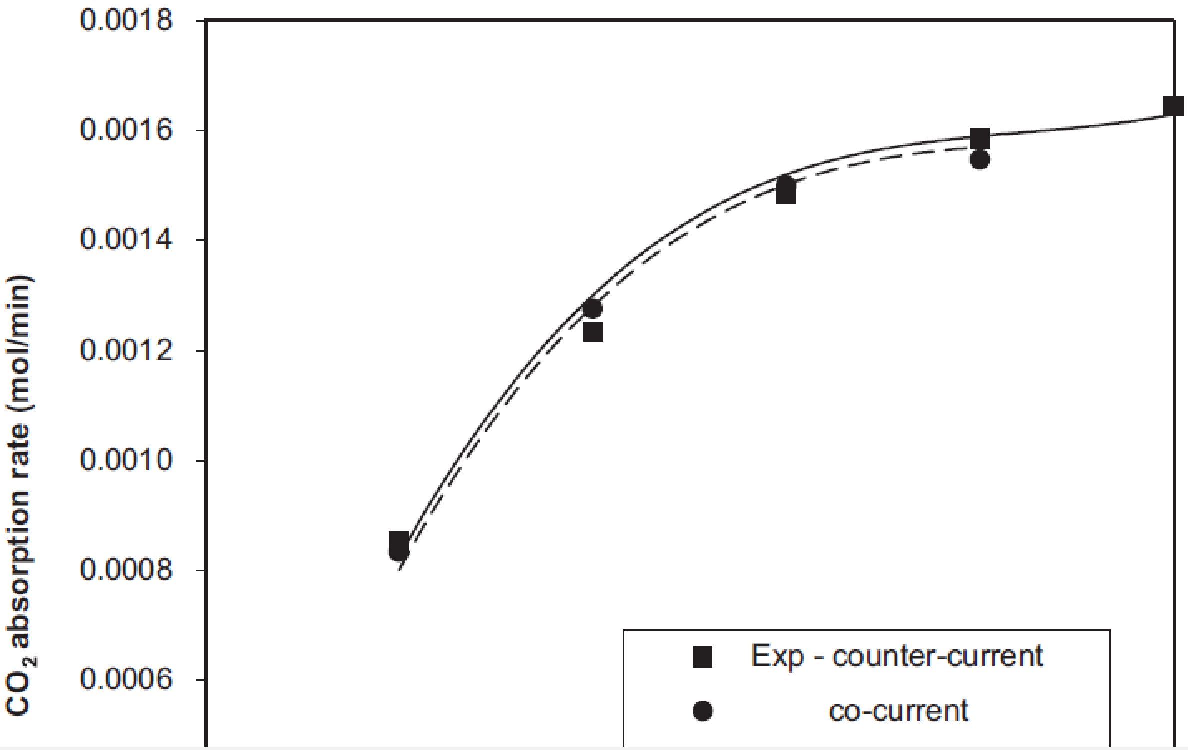
CO_2

MEA

Fig. 14. Model solution and the concentration gradient of CO_2 (mol m^{-3}) at 50 bar using 0.5 M MEA as the absorbent solvent while considering partial-wetting (1%).

Faiz et al. / Journal of Membrane Science 365 (2010) 232-241

Counter-current?



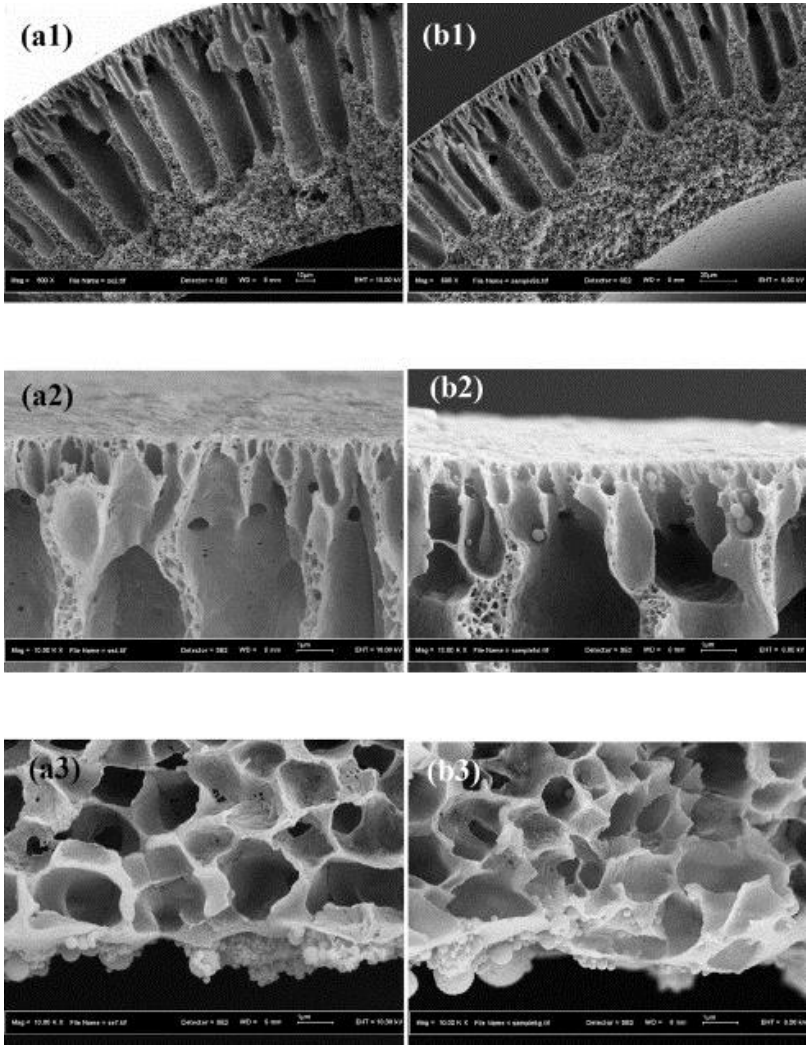
….. Small pressure difference can provide enough CO2 capture rate, the little higher pressure induced by counter-current flow is less important than increasing operation flexibility in real plant.…

vol% CO_2

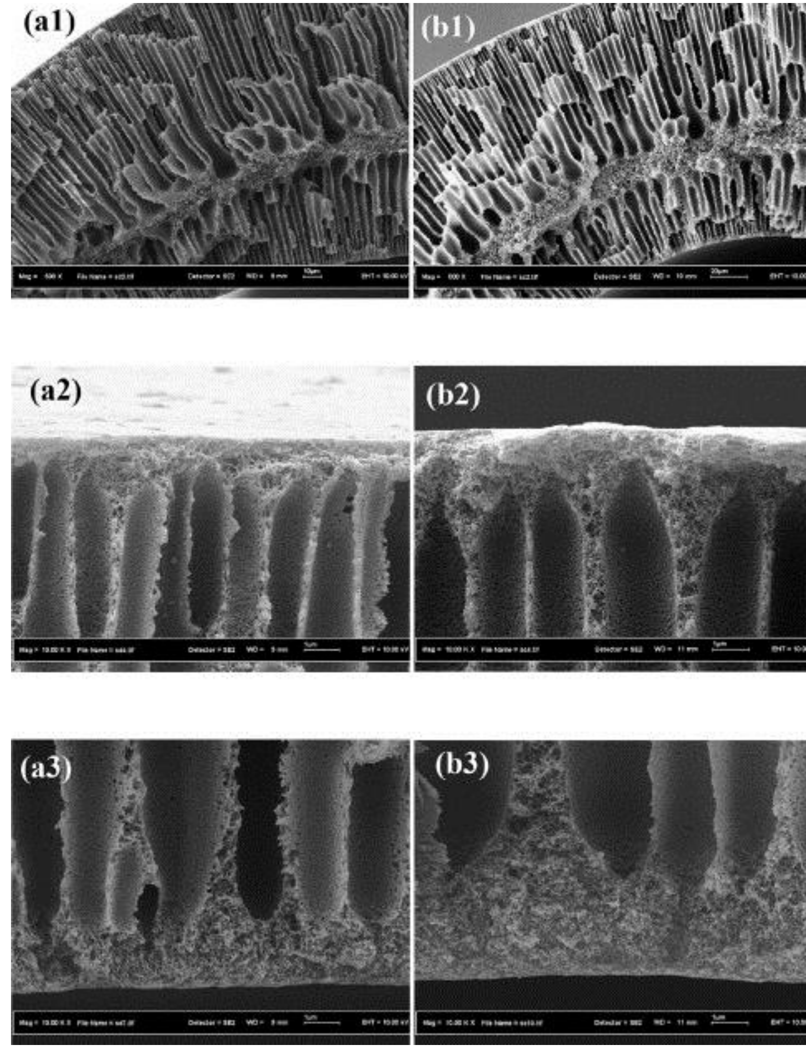
Fig. 11. Predicted versus experimental CO_2 absorption rate in a 3-FSMC (PTFE) – CO_2/AHPD-Pz system (gas flow rate of 100 ml/min; liquid flow rate of 20 ml/min).

Bougie et al. / Chemical Engineering Science 123 (2015) 255–264

Microporous?



The structure of PVDF hollow fiber membranes for (a) plain and (b) with PEG (1) cross section, (2) shell side, and (3) lumen side.



The structure of PEI hollow fiber membranes (a) plain and (b) with PEG (1) cross section, (2) shell side, and (3) lumen side.

Naim et al. / Chemical engineering research and design 9 2 (2 0 1 4) 1391–1398

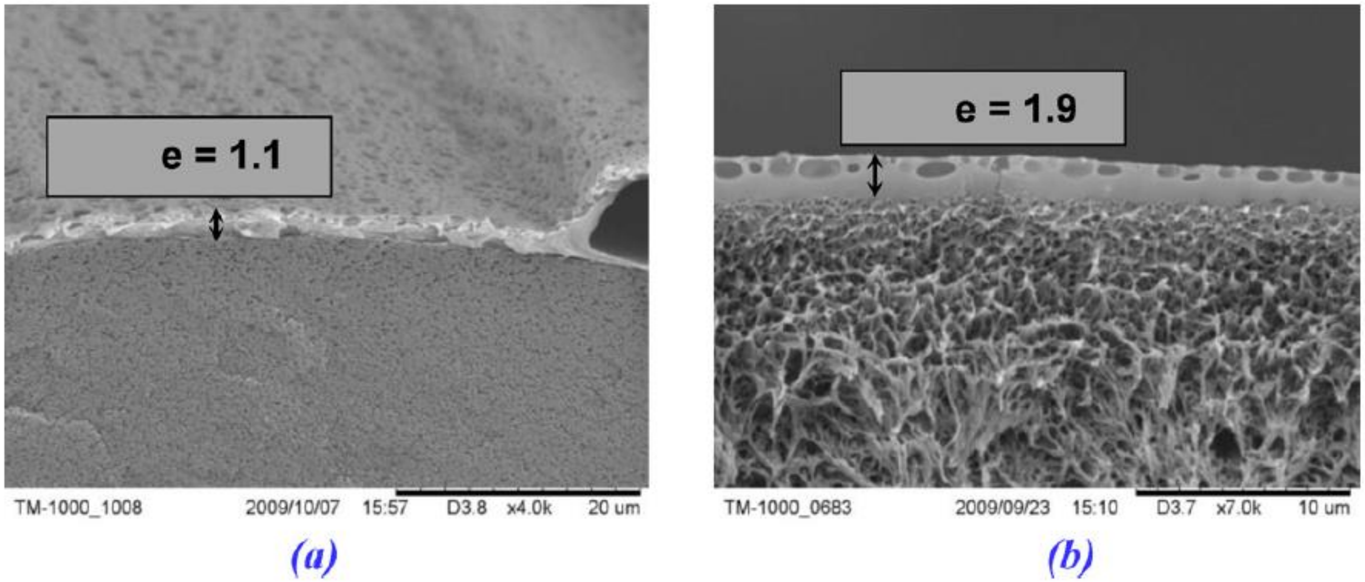


Fig. 7. SEM pictures (cross section) of the two different types of composite hollow fibers prepared and tested in this study. (a) Teflon AF 2400 average coating thickness 1.1 μm (Oxyphan_TF). (b) PTMSP average coating thickness 1.9 μm (Oxyphan_PTMSP).

Mechanically stronger top layer?

Nguyen et al. / Journal of Membrane Science 377 (2011) 261– 272

Concluding remarks

How to prevent the membrane from wetting in the long term operation?

- Hydrophobic membranes
- Surface modification of membranes
  (hydrophobicity, chemical resistance)

- Composite membranes
- Selection of denser membranes

- Selection of liquids with suitable surface tension

- Optimization of operation conditions/technique

How to increase operation flexibility?

- How to increase allowable transmembrane pressure (liquid & gas break-through pressure)?

- Reducing operation cost
- Reducing installation cost
- Reducing expected process complexity

(subtle control of transmembrane pressure over hundreds of large modules, ready for break-through of liquid and gas)

Thank you!