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Modelling the mass transfer in membrane contactors operated with highly viscous amine absorbents

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The Research Council of Norway

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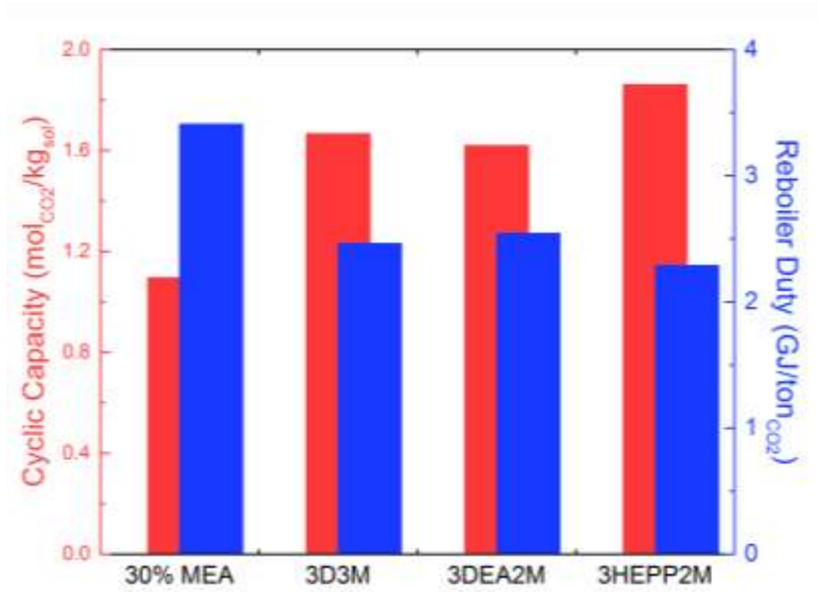
3GMC PROJECT

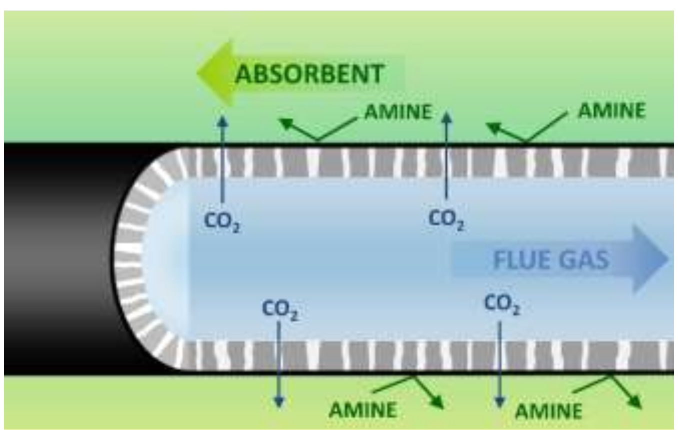


GOAL: Reduce CO_2 capture cost

APPROACH: Solvents with lower energy duty

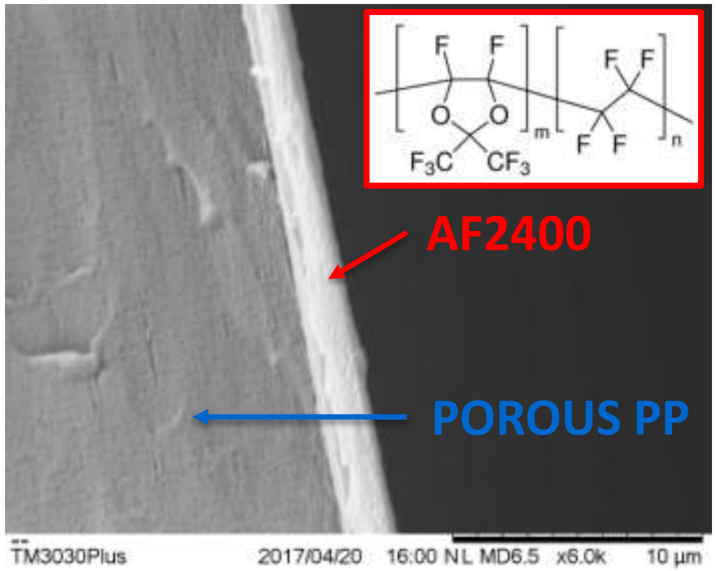
DRAWBACK: High solvent volatility

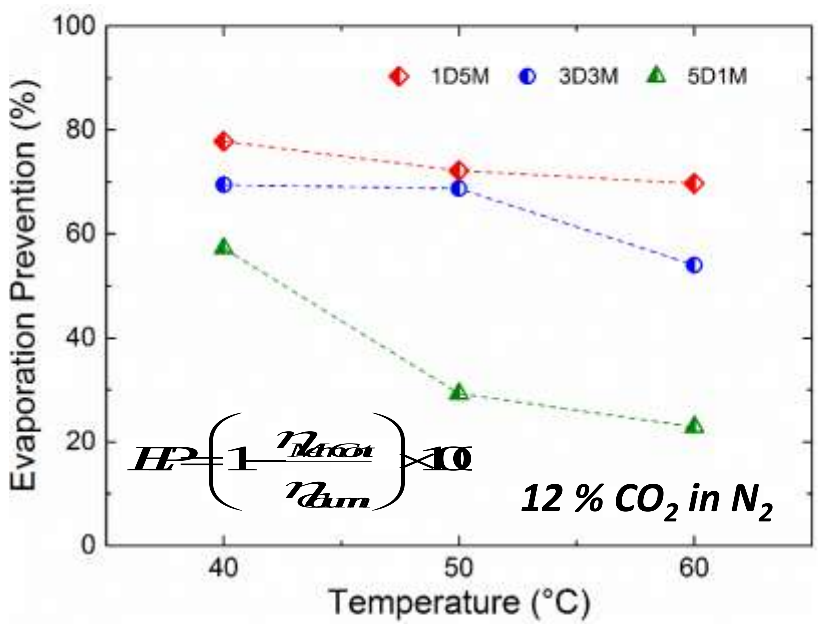
SOLUTION: Non-Porous Membrane Contactors

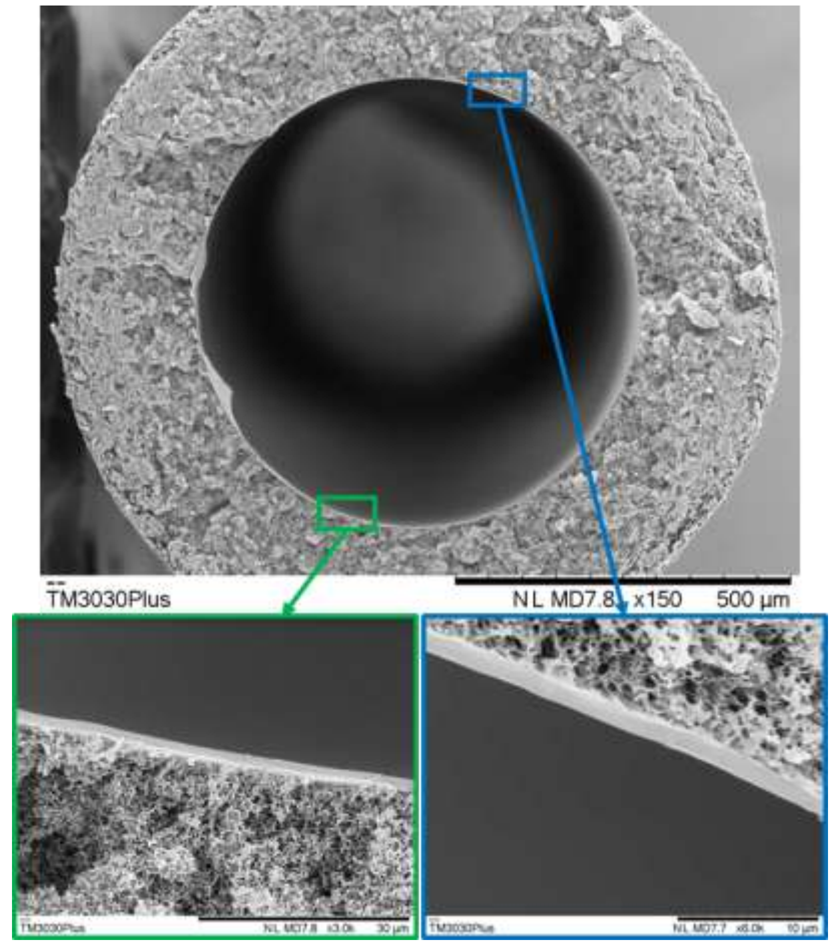


Patent WO 2017055615 A1

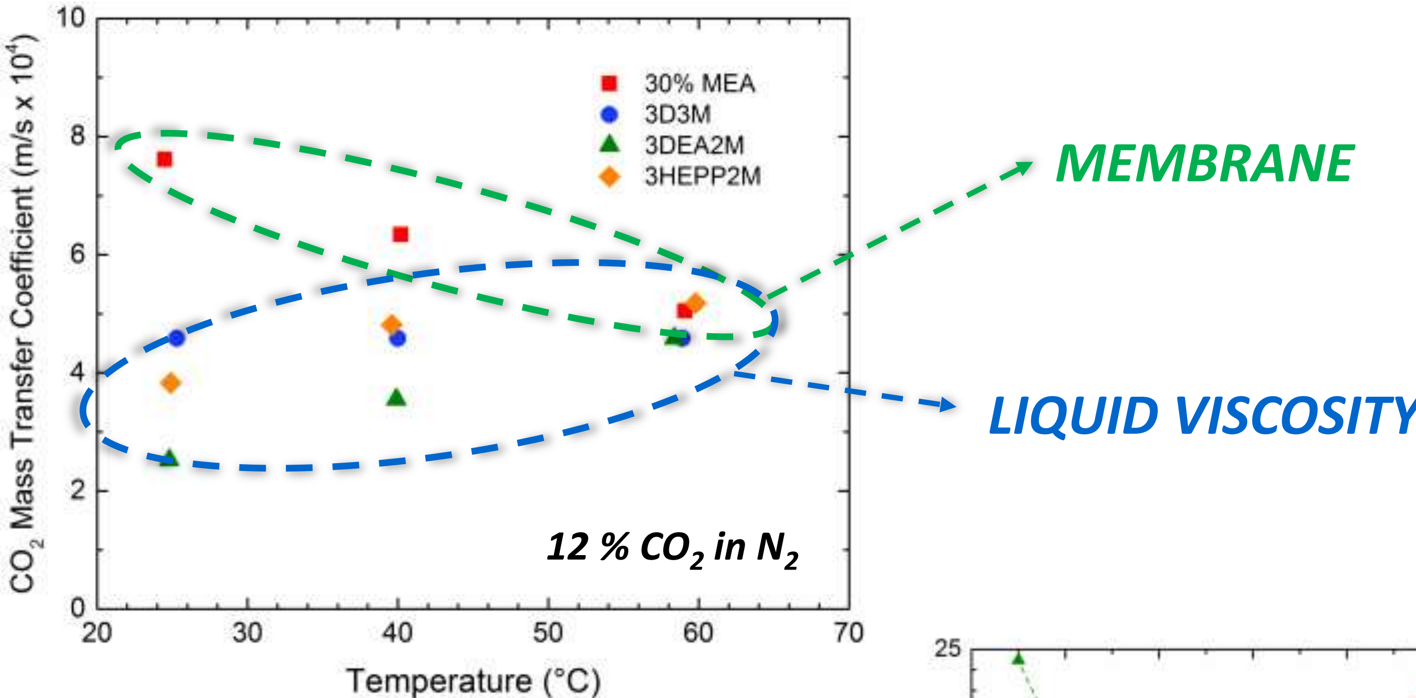
3GMC PROJECT







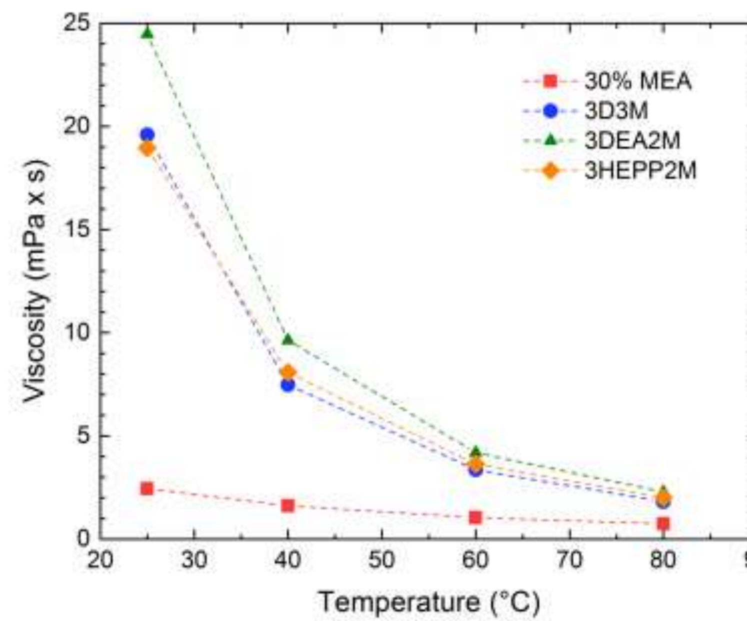
MEMBRANE CONTACTOR TESTS



3G SOLVENTS vs AQUEOUS MEA

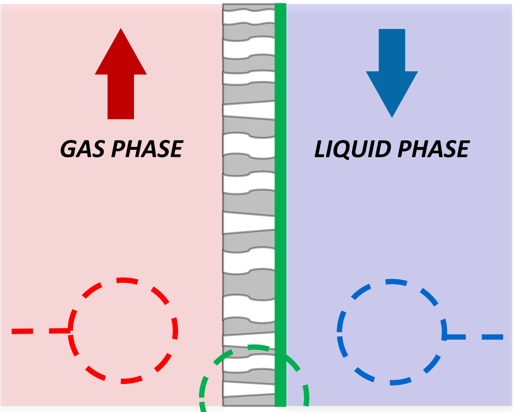
Compared to 30 wt% MEA, the new solvents have:

1. ***Higher CO_2 solubility***
2. ***Faster CO_2 kinetics***



RESISTANCE IN SERIES MODEL

$$\frac{1}{k_{ov}} = \frac{1}{k_g} + \frac{1}{k_m} + \frac{1}{k_l}$$



$$\frac{1}{k_g} = \left(\frac{D_{AB}}{d_h} 0.023\, Re^{0.8} Sc^{0.33}\right)^{-1}$$

$$D_{AB} = \frac{10^{-3} T^{1.75} \left(\frac{1}{MW_A} + \frac{1}{MW_B}\right)^{0.5}}{p\left[\left(\sum_A \upsilon_i\right)^{1/3} + \left(\sum_B \upsilon_i\right)^{1/3}\right]^2}$$

$$\frac{1}{k_l} = \frac{1}{mEk_l^0}$$

$$mEk_l^0 = m\sqrt{D_{CO_2} \cdot k_{obs}}$$

$$D_{CO_2} = D_{H_2O}\left(\frac{\mu_{H_2O}}{\mu_{abs}}\right)^{0.8}$$

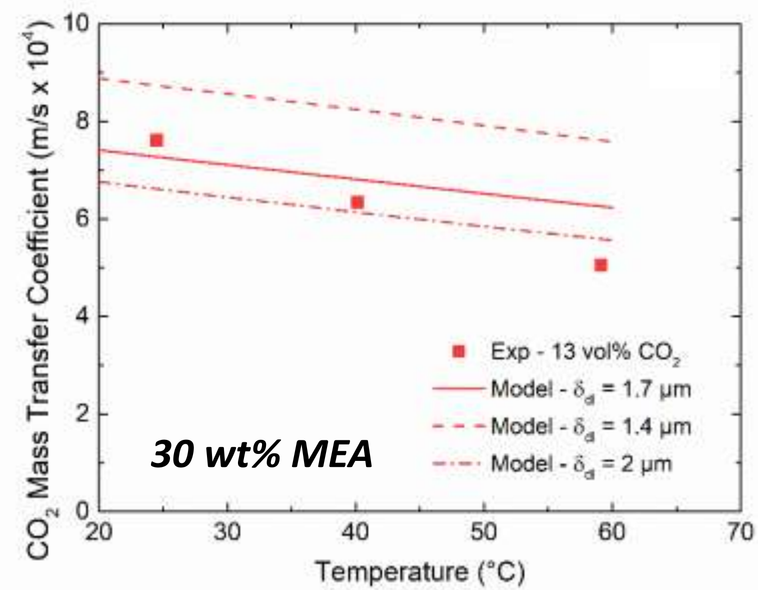
$$\frac{1}{k_m} = \left(\frac{\ell_{ps} \cdot \tau}{D_g \cdot \varepsilon} + \frac{\ell_{dl} \cdot v_m}{PRT}\right)$$

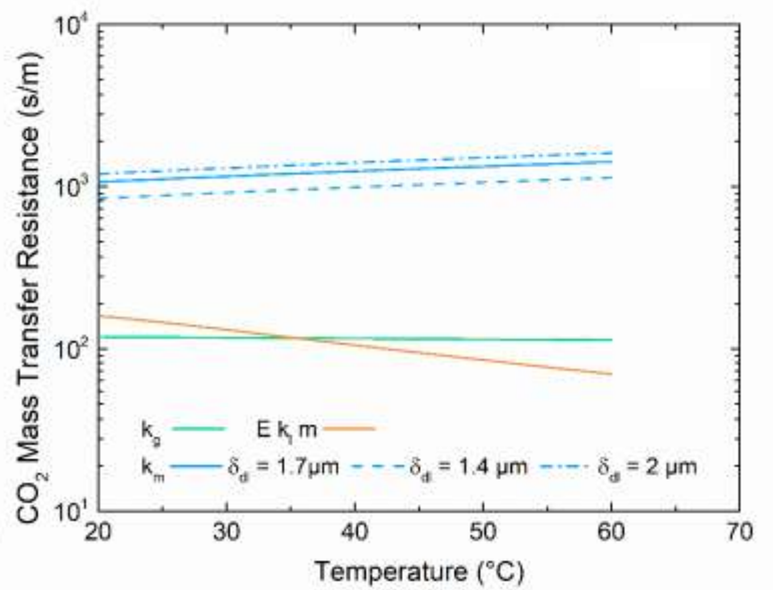
$\varepsilon = 41\%$ $T = 25 - 60\ °C$

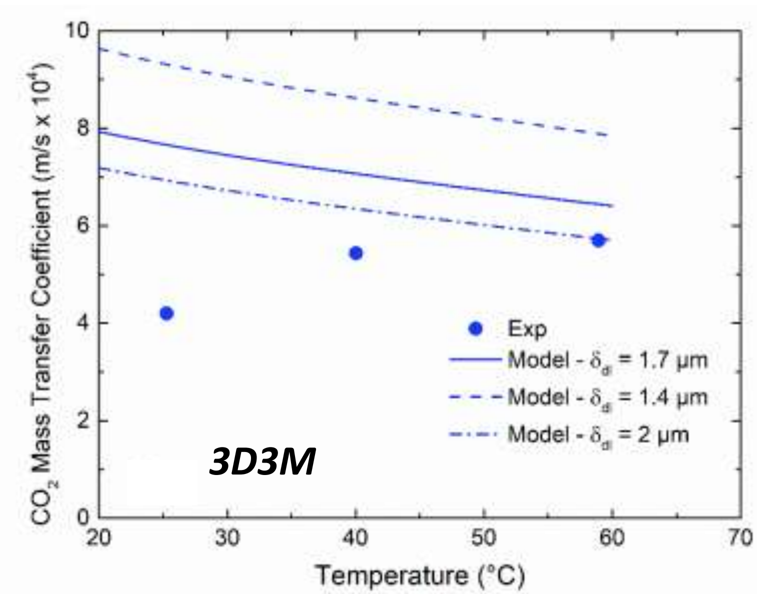
$\tau = 15$ $P = \sim 3000$ Barrer

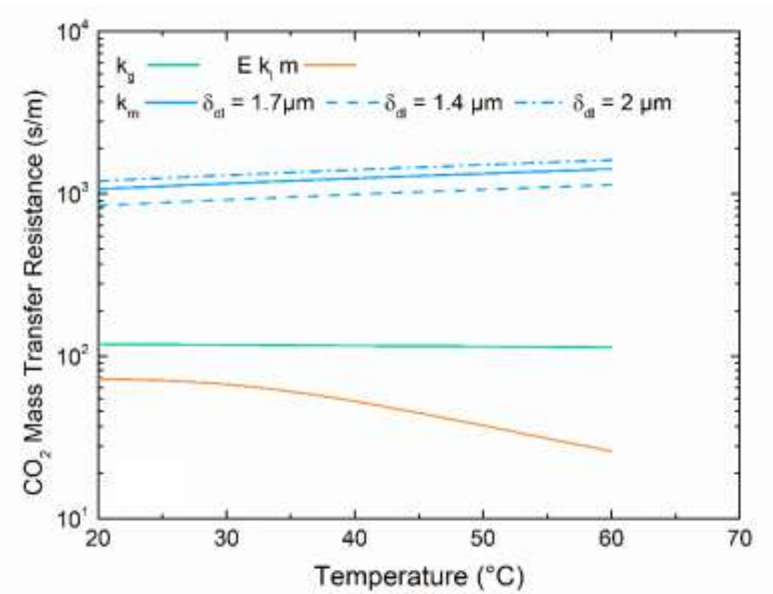
$\ell_{ps} = 25\mu m$ $\ell_{dl} = 1.5\ \mu m$

MODELLING DATA

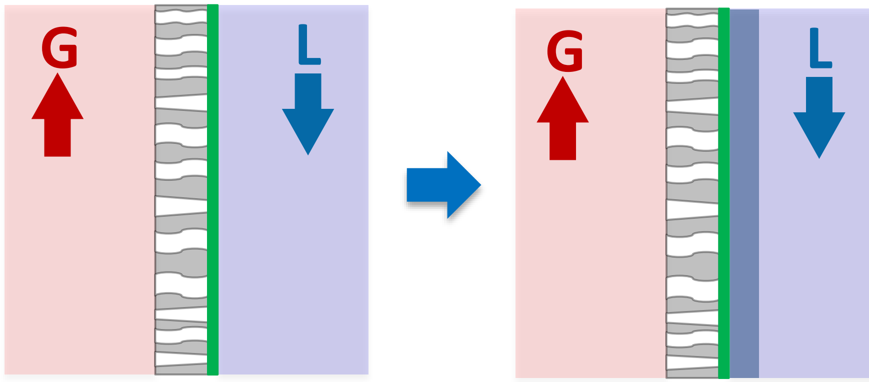








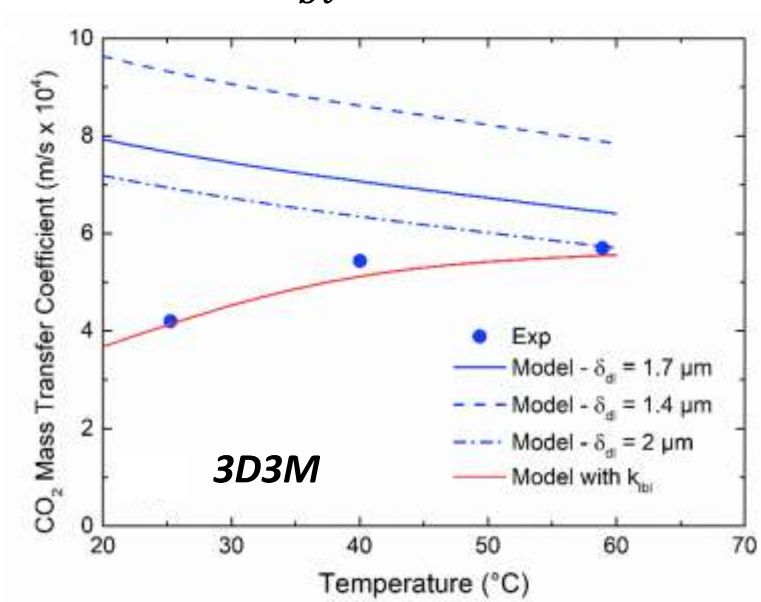
MODELLING VISCOUS SOLVENTS

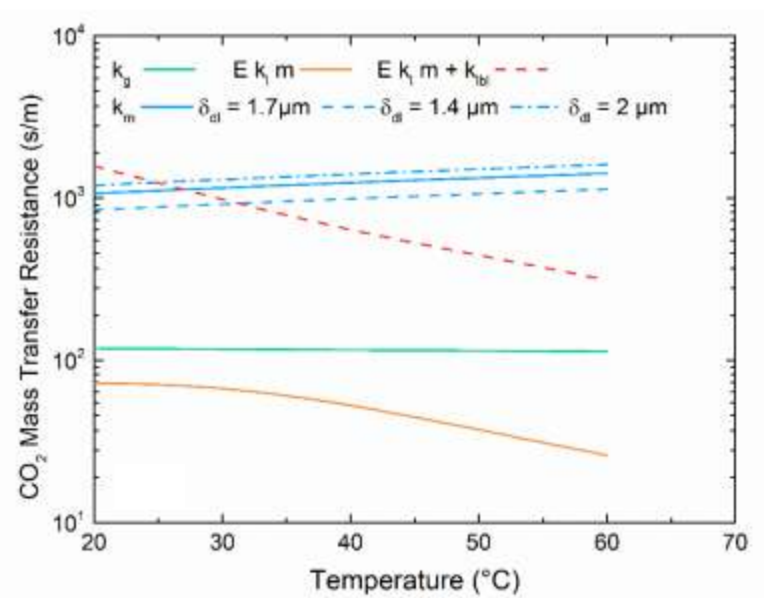


$$\frac{1}{k_{ov}} = \frac{1}{k_g} + \frac{1}{k_m} + \frac{1}{k_l} + \frac{1}{k_{bl}}$$

$$k_{bl} = \frac{\ell_{bl} \cdot v_m}{m\, D_{CO2,sat}\, R\, T}$$

$$l_{bl} = 150\ nm$$



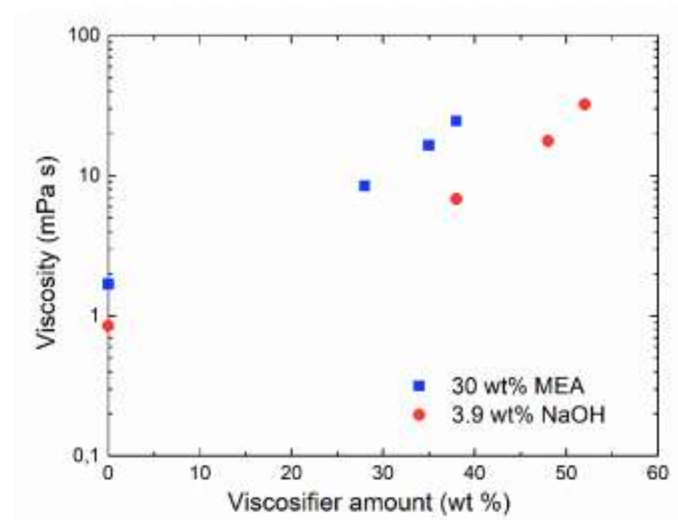


CONTROLLED VISCOSITY INCREASE

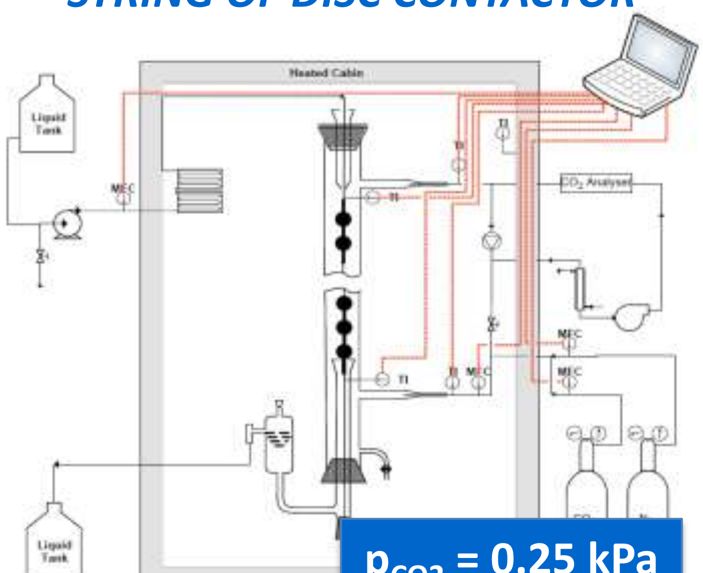
A viscosifier (sugar) added to 30 wt% MEA and 3.9 wt% (1M) NaOH aqueous solution

Determine the liquid parameters needed for the resistance in series model

$$\frac{1}{k_{ov}} = \frac{1}{k_g} + \frac{1}{k_m} + \frac{1}{m\ E\ k_{l,0}}$$

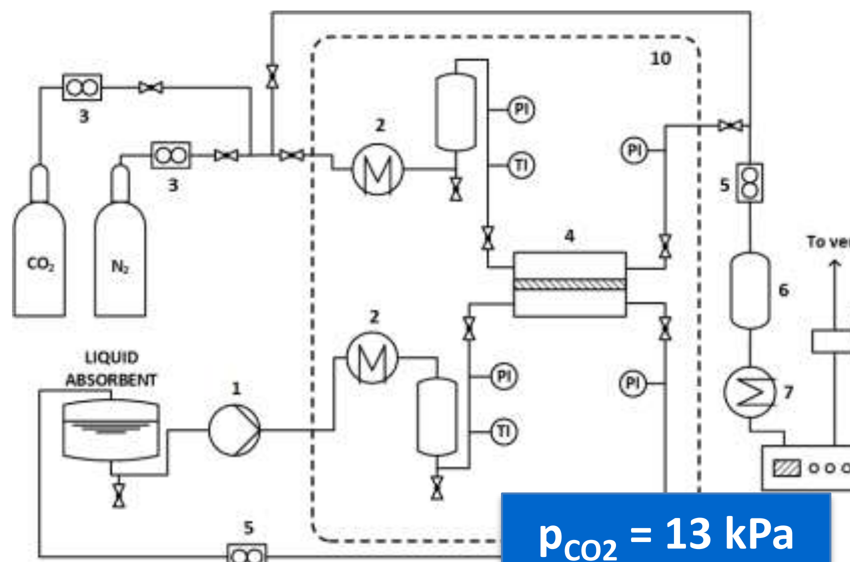


STRING OF DISC CONTACTOR



p_{CO2} = 0.25 kPa

MEMBRANE CONTACTOR



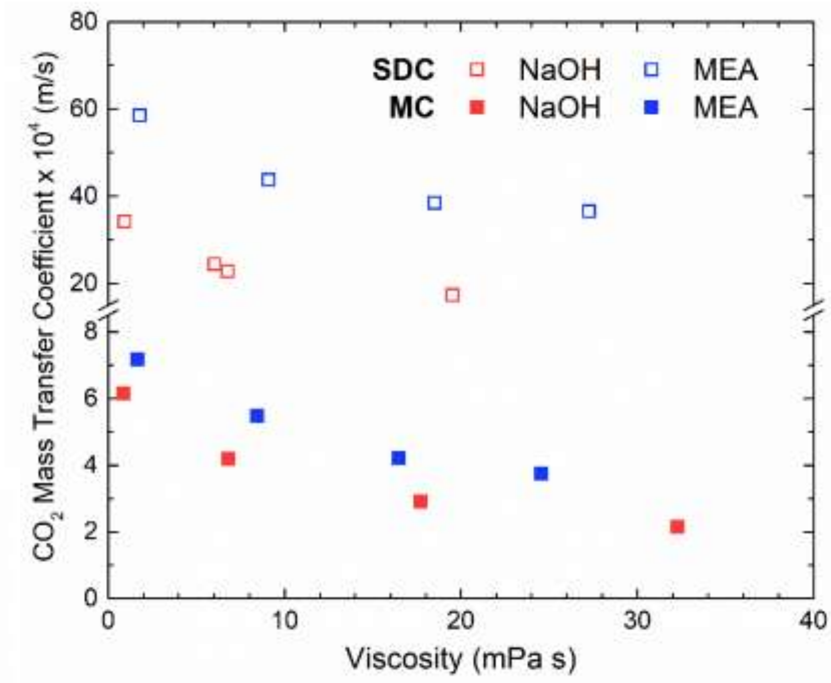
p_{CO2} = 13 kPa

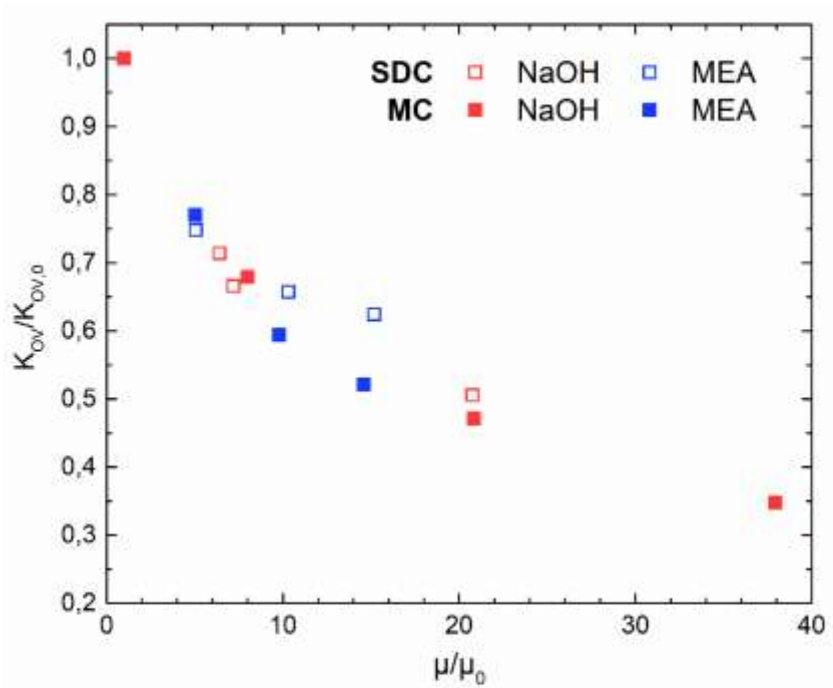
CONTROLLED VISCOSITY INCREASE

Mass transfer coefficient dropped in the SDC along with viscosity

↓

In the MC the membrane phase adds additional resistance to the transport

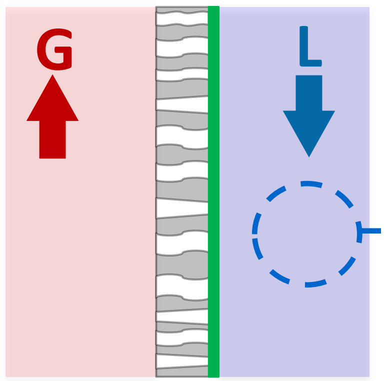




The CO_2 mass transfer coefficient drops with viscosity:

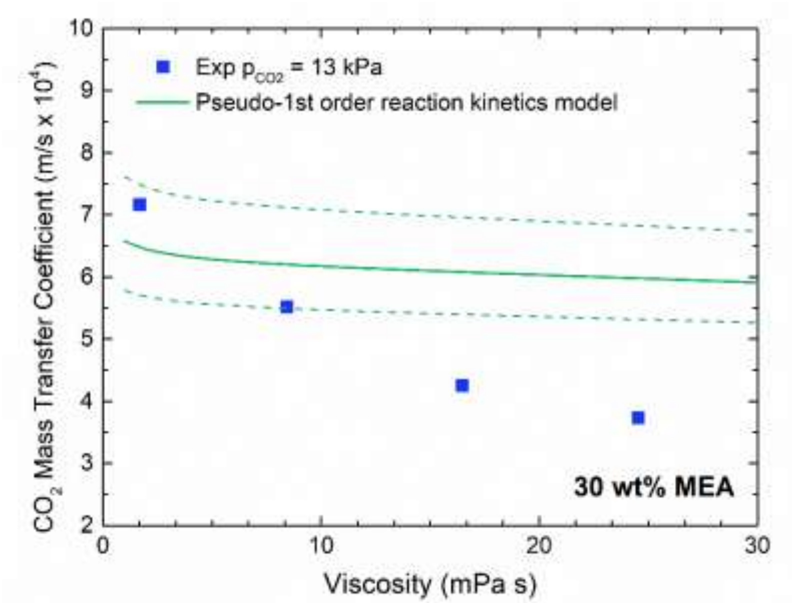
1. ***Independently from the absorbent nature***
2. ***Independently from the absorption characteristics***

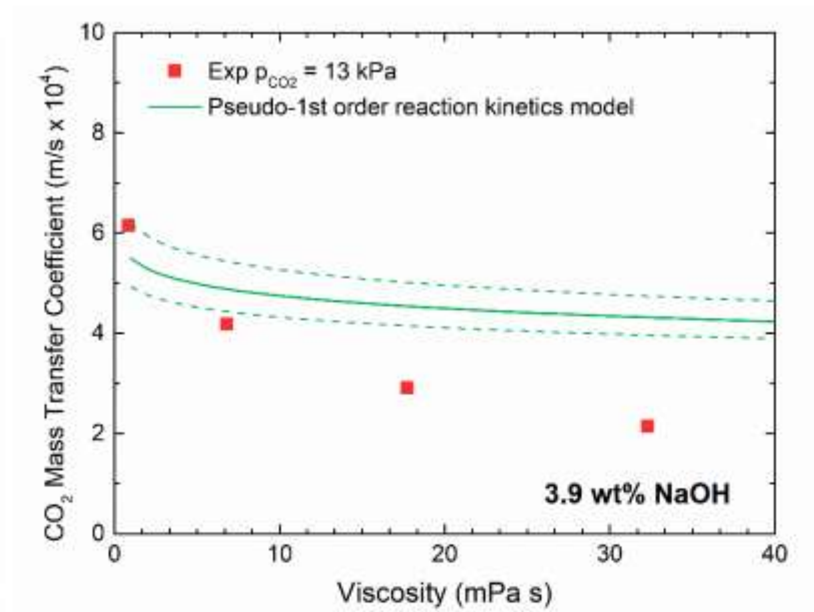
MODELLING RESULTS



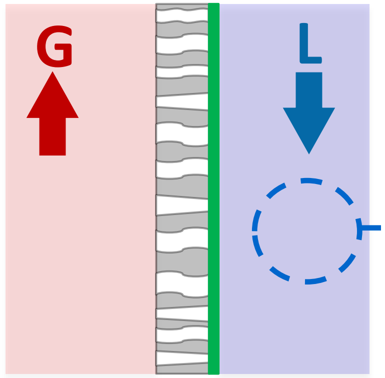
$$\frac{1}{k_l} = \frac{1}{mEk_l^0} = \frac{1}{m\sqrt{D_{CO_2} \cdot k_{obs}}}$$

Directly from SDC





MODELLING RESULTS



$$\frac{1}{k_l} = \frac{1}{mEk_l^0} = \frac{1}{m\sqrt{D_{CO_2} \cdot k_{obs}}}$$

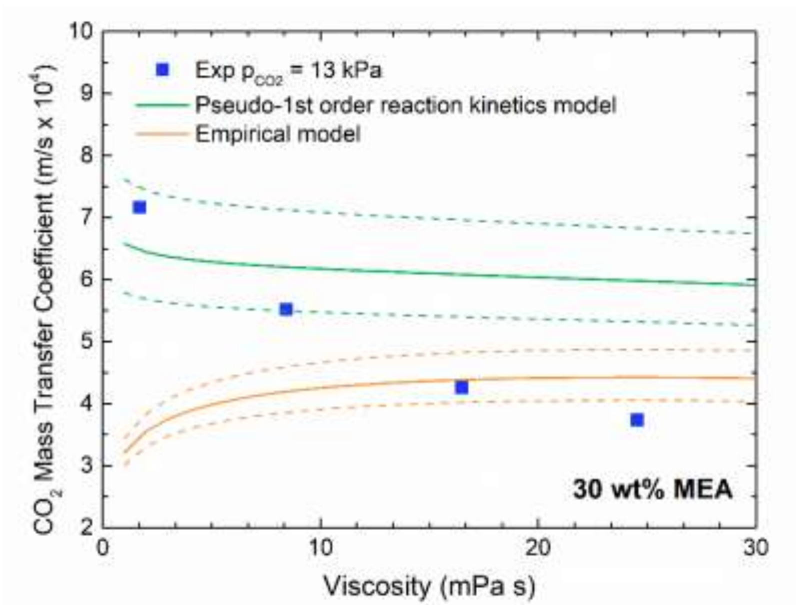
Directly from SDC

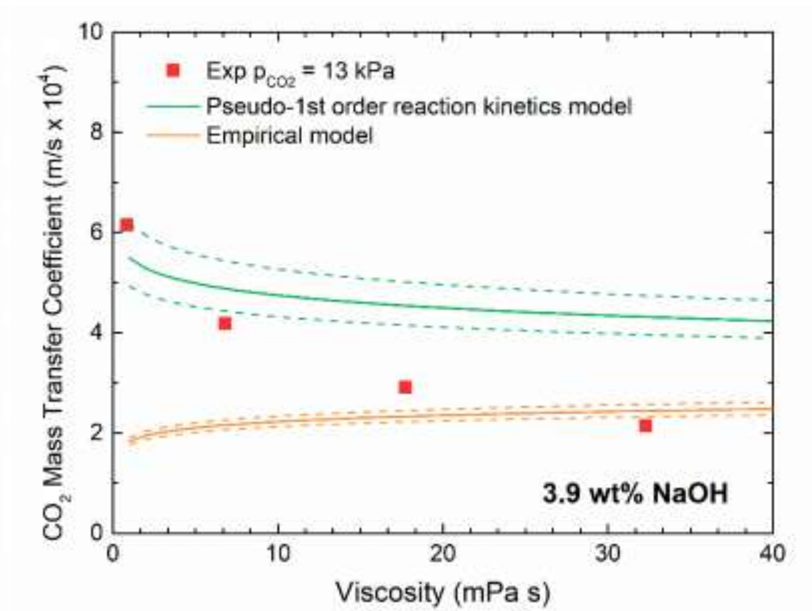
$$\frac{1}{k_l} = \frac{1}{mEk_l^0}$$

From SDC

$$k_l^0 = \frac{D_{CO2,l}}{d_h} \cdot 1.62 \left[\frac{d_h}{H} Re_l Sc_l\right]^{1/3}$$

Leveque Correlation





CONCLUSIONS

When viscous solvents (μ > 5 mPa·s) are used as liquid phase in membrane contactors:

1. *The Resistance in Series Model is not reliable to describe the mass transport in membrane contactors*
2. *The boundary layer resistance dominates the mass transport, limiting the availability of amines at the interface*
3. *Parameters obtained from lean viscous solvent absorption tests are not representative for membrane contactor*
4. *2D models must be used to account for the boundary layer effect, although they require more parameters and more complex computational efforts*

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NEW CONCEPTS FOR CO_2 CAPTURE

THANK YOU!

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