Microfluidic Application in Carbon Capture

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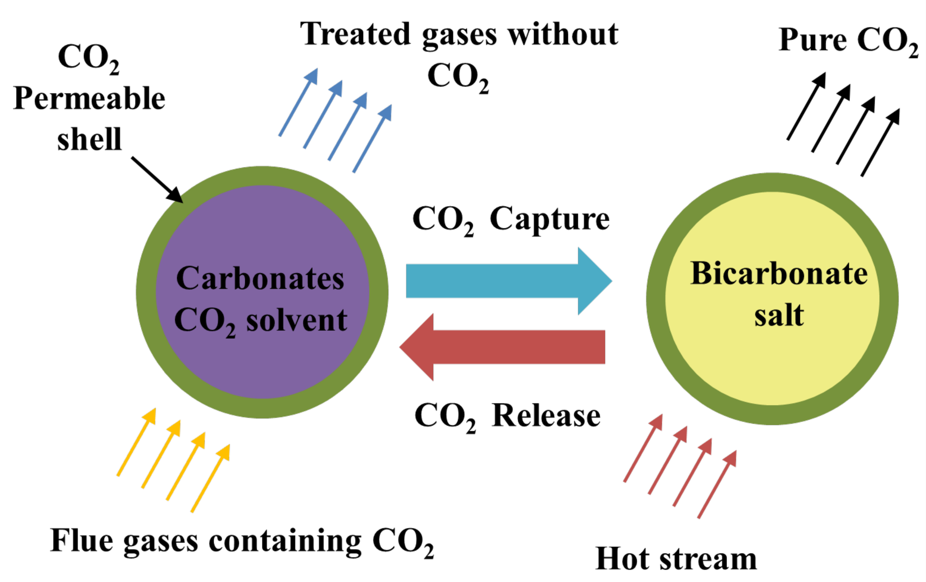
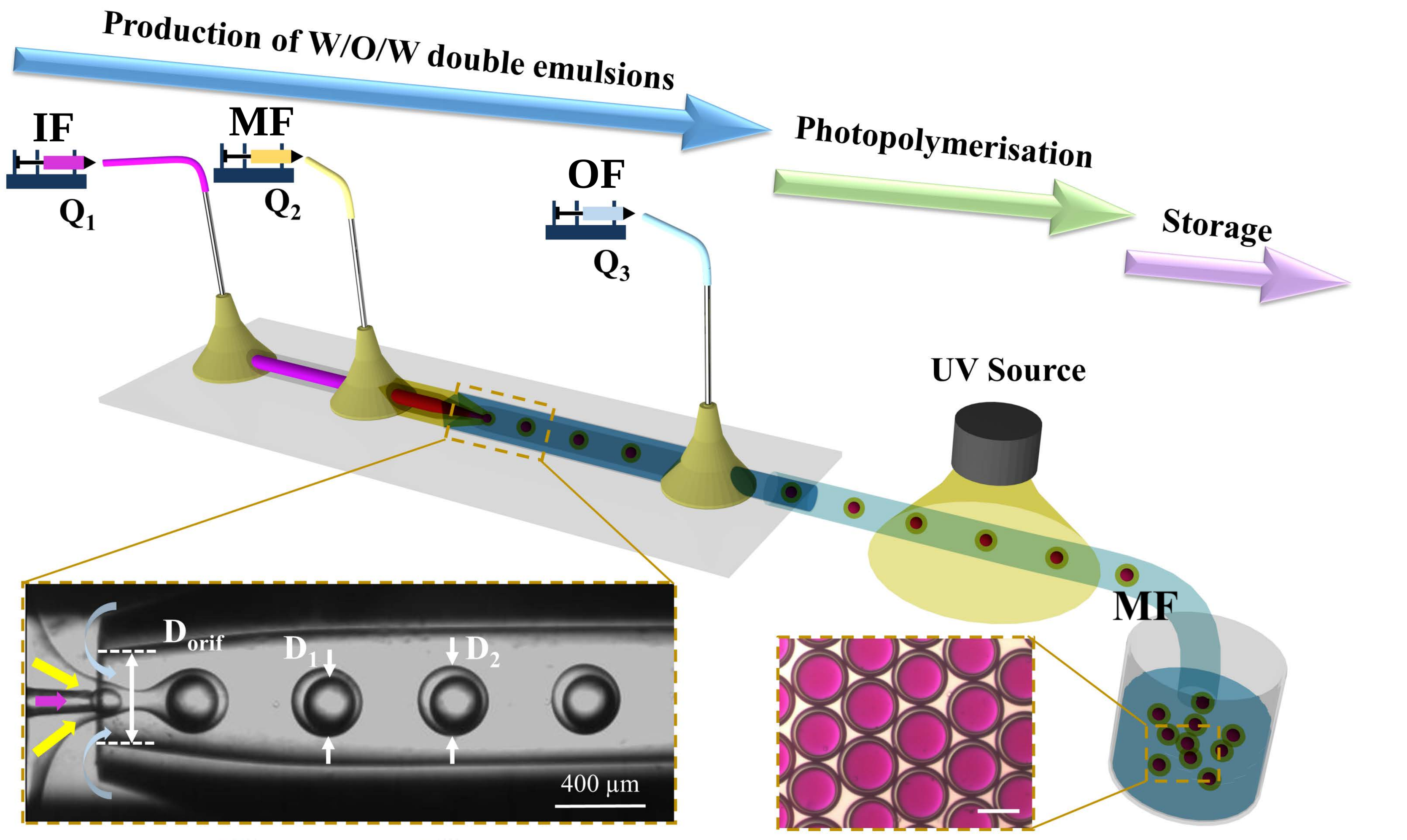
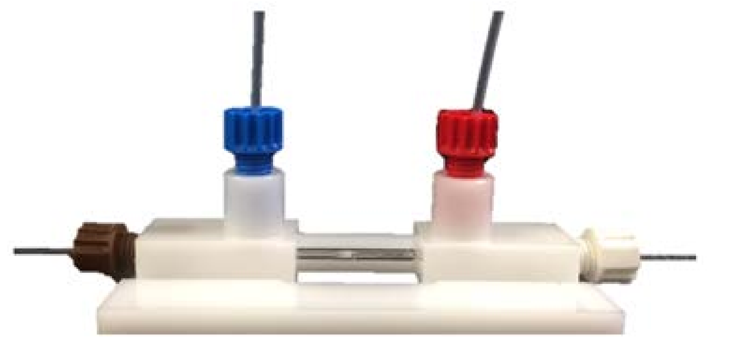
Introduction

Excessive concentration of atmospheric CO_2 has significantly contributed to global warming. Carbon capture and storage is the most viable approach for decreasing the amount of CO_2 released into the atmosphere. Monoethanolamine (MEA) scrubbing is the most commercially proven approach for CO_2 capture. However, MEA is corrosive and degrades during repeated regeneration cycles at elevated temperatures into the products that pose a hazard to human health and the environment. Encapsulating CO_2 solvents (such as MEA within carbonates) within CO_2 permeable shell is a novel technique that prevents evaporation of solvent and its direct contact with the capture system, and provides much higher surface area-to-volume ratio, in comparison to typical packed towers [1].



Methodology





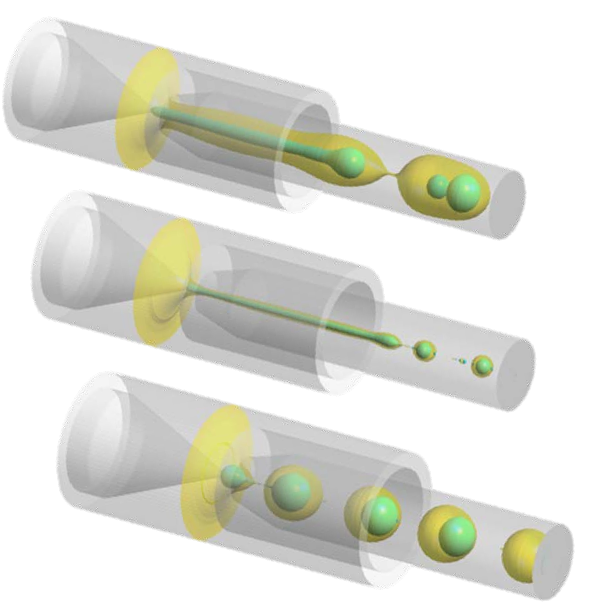
IF: 5-30 wt% aqueous K_2CO_3 solution
MF: 0.5 wt% Dow Corning® 749 Fluid in a UV-curable silicon rubber.
OF: 70 wt% glycerol + 0.5 wt% Pluronic® F-127 in water.

Numerical modelling

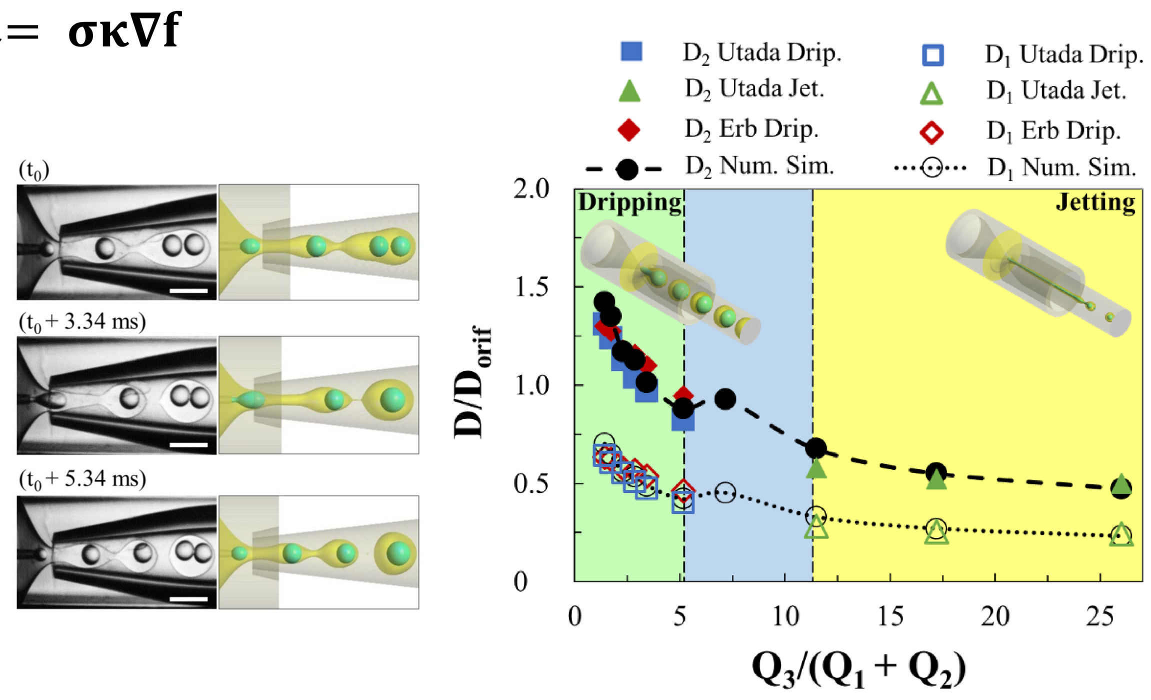
A two-dimensional incompressible axisymmetric numerical model based on volume of fluid - continuum surface force (VOF-CSF) approach was developed to study the hydrodynamics of double emulsion formation.

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho U_i)}{\partial x_i} = 0 \qquad \frac{\partial(\rho U_i)}{\partial t} + \frac{\partial(\rho U_i U_j)}{\partial x_j} = -\frac{\partial P_i}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial U_i}{\partial x_j}\right) + F_\gamma$$

$$\frac{\partial f}{\partial t} + \frac{\partial(U_i f)}{\partial x_i} = 0 \qquad F_\gamma = \sigma \kappa \nabla f$$

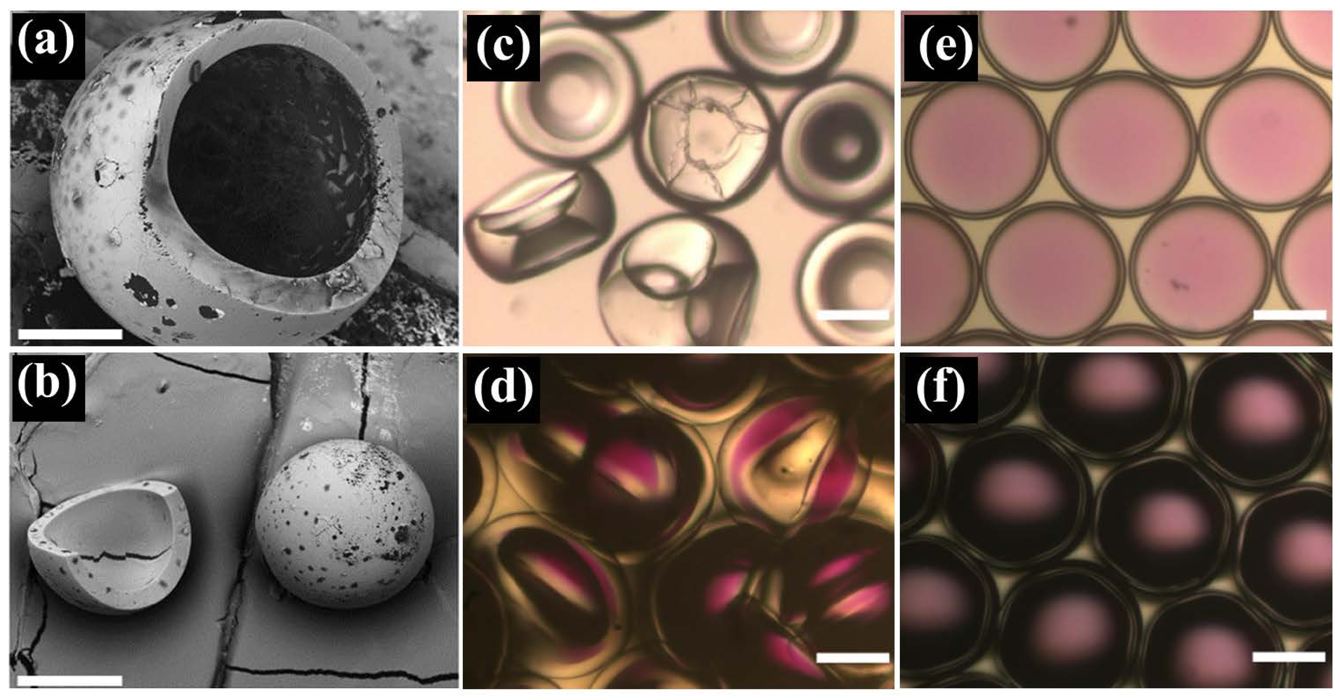


Numerical results

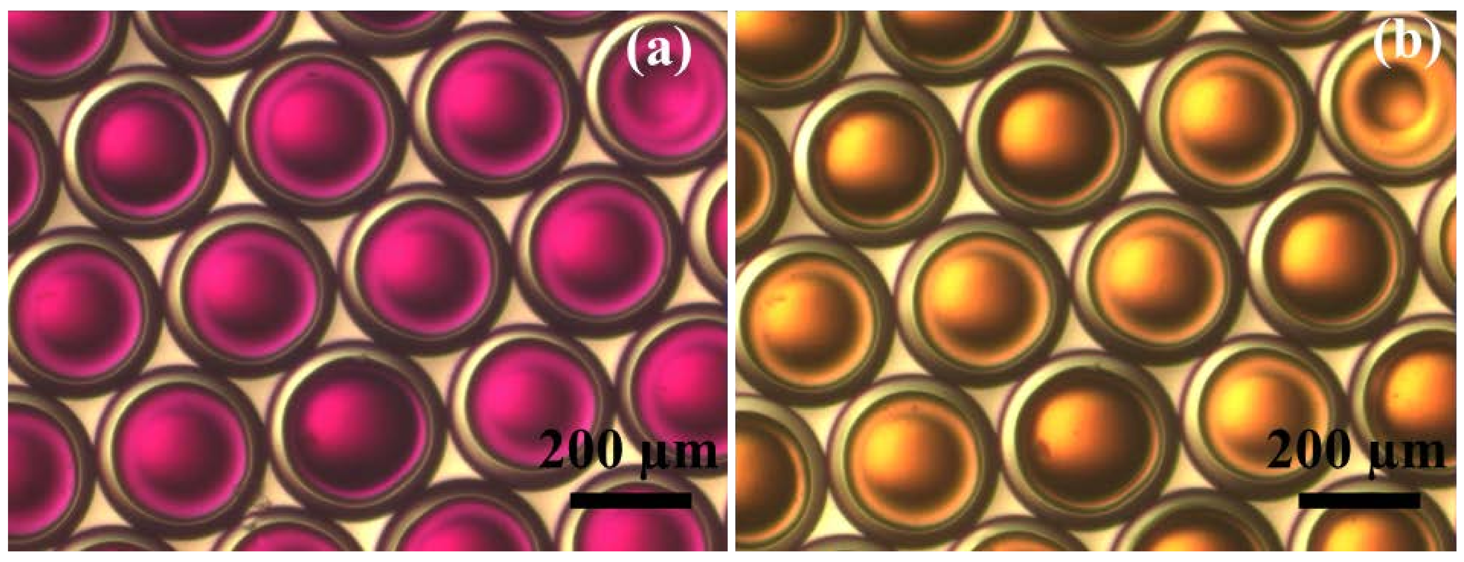


Comparison of numerical model with experimental and analytical data [2-4]

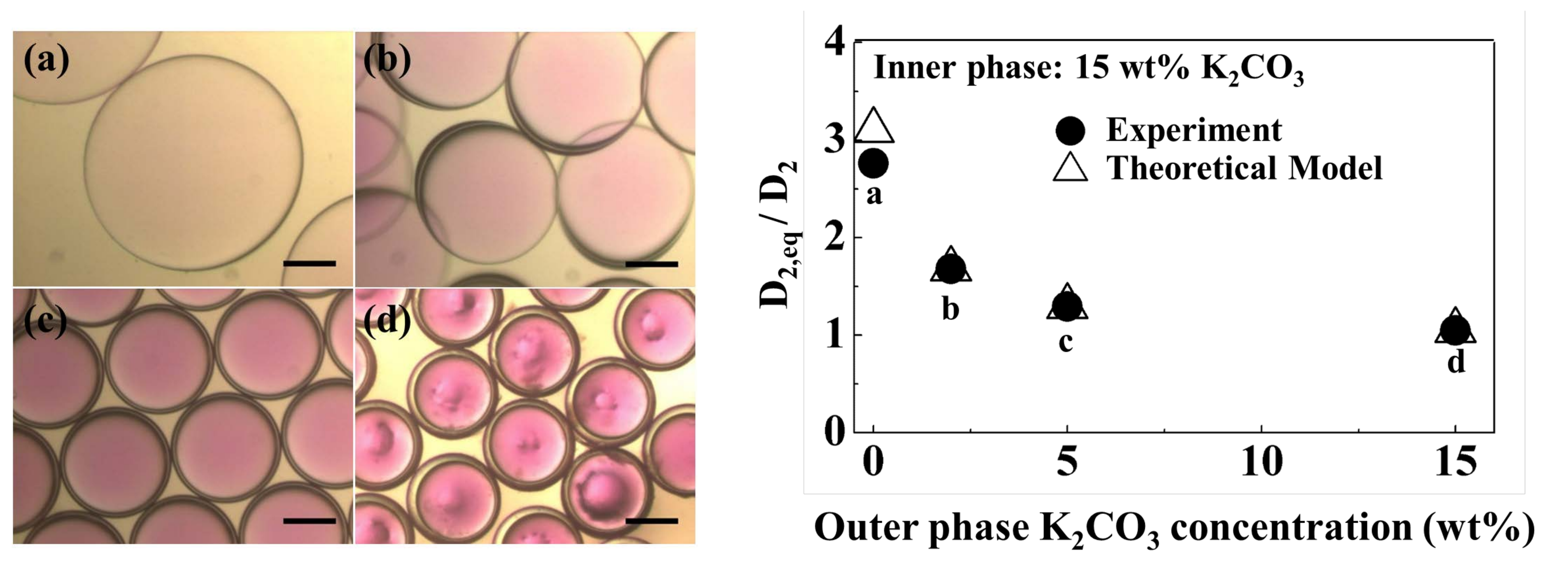
Experimental results



(a & b) SEM images of microtome cross-sectioned capsules; (c) collapsed capsules synthesised without DC 749 in the middle phase; (d) dehydrated buckled capsules with 15 wt% K_2CO_3 in the core after 6 h of exposure to ambient air; (e) 15 wt% K_2CO_3 capsules before capillary-induced cavitation; (f) 15 wt% K_2CO_3 capsules with cavitation-formed vapour bubble; The scale bars: (a) 100 µm; (b-f) 200 µm.



The capsules containing 5 wt% K_2CO_3 and m-cresol purple (pH indicator) in the aqueous core: (a) prior to CO_2 capture; (b) after CO_2 uptake



The effect of osmosis on the capsule size. Following is a theoretical model to predict the equilibrium size of capsules, $D_{2,eq}$, under the osmosis effect. C_{out} and C_{in} are the initial molarity of the storage solution and inner phase. R, T, i, E, t, and t_{eq} are gas constant, temperature, van 't Hoff factors, elastic modulus, initial shell thickness, and shell thickness in equilibrium respectively.

$$(KC_{out})\beta^4 + (1 - KC_{in})\beta - 1 = 0$$

$$\beta = D_{1,eq}/D_1 \qquad K = D_1\, RTi/8tE \qquad t_{eq} = (1/\beta)^2 t$$

Conclusions

- A single-step microfluidic method for continuous production of microcapsules with elastic semipermeable shells was developed and used to encapsulate liquid sorbents, particularly highly alkaline solutions
- To achieve 100% encapsulation efficiency of the core liquid, the middle phase should contain 0.5-2 wt% DC 749 stabiliser.
- The minimum energy density and UV light irradiance needed for complete shell polymerisation were 2 $J\cdot cm^{-2}$ and 13.8 $mW\cdot cm^{-2}$, respectively.
- CO_2 capture capacity of the 30 wt% K_2CO_3 capsules was 1.6-2 mmol/g, depending on their size and shell thickness.

References

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