Fabrication of Core-shell Hydrogel Particles via In-air Microfluidics for CO_2 Capture

Yiwei Long[a], Jieke Jiang[a], Claas Willem Visser[a], Wim Brilman[b], Wilko Rohlfs[a]
a: Department of Thermal and Fluid Engineering, University of Twente, Enschede, 7522 NB Netherlands
b: Sustainable Process Technology, Faculty of Science and Technology, University of Twente, Enschede, 7522 NB Netherlands

Introduction

- Global emission of CO_2 has been rising at an alarming rate since the last century (5 – 35 billion tons per year), escalating global warming;
- Since the strategy of Carbon Capture and Storage (CCS) was proposed, amine-based solvents are commonly used for CO_2 capture, which demonstrate promising CO_2 capacity yet have inevitable drawbacks including thermal degradation, toxic emission, large energy cost for regeneration, etc.
- Amine-based solid sorbents for CO_2 capture have received extensive attention as they do not suffer from the problems above but still display satisfying capability of capturing CO_2.
- In-air microfluidics enables a large-scale production of Polyethylenimine (PEI) hydrogel particles in a low-cost and controllable way [1].

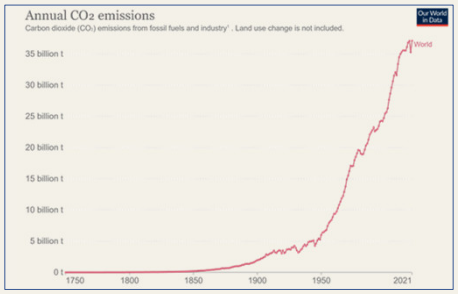
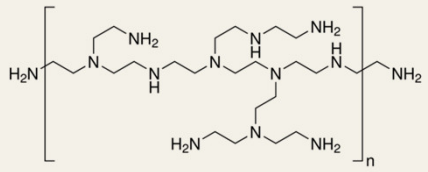
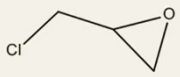


Fig 1. CO_2 emissions from fossil fuels and industry - Worldwide

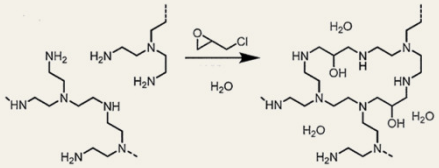
Materials



Branched PEI



Epichlorohydrin (ECH) crosslinker



Crosslinking reaction

- Branched PEI solution (20 wt%) is mixed with ECH to prepare the ink which could result in fast crosslinking;
- Hydrophobic silica (AEROSIL R972) dissolved in Tetrahydrofuran is used as the coating layer to prevent particle agglomeration.

In-air microfluidics production

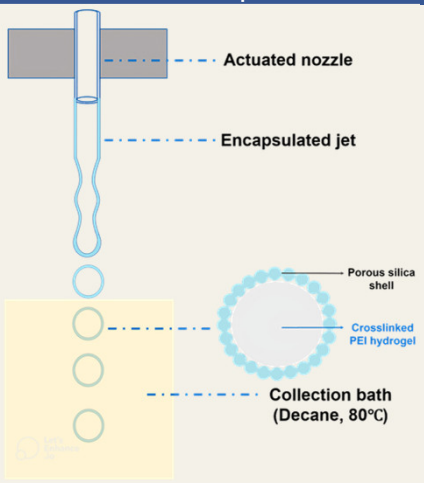


Fig 2. Encapsulated jet breaking into droplets with a core-shell structure

- A core-shell nozzle is used where the core ejects the PEI solution with the crosslinker and the shell ejects the silica suspension;
- The compound jet then breaks into monodisperse core-shell droplets by forced Rayleigh-Plateau breakup[1];
- The high inertia of the ejected core jet pulls a thin film of the surrounding suspension that is supplied by the shell nozzle[2], resulting in a core-shell structure of droplets Fig 3;
- By using a collection bath with Decane (at 80° C) as the solvent, the droplets are collected and further crosslinked into solidified particles as shown in Fig 3.

Solidified hydrogel particles

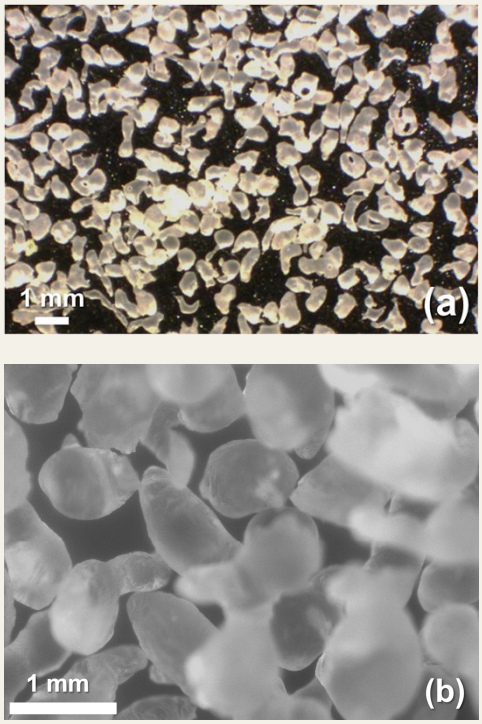


Fig 3. Crosslinked particles after drying: (a) zoom out; (b) zoom in

Diffusion-reaction model

- *Shell resistance*

$$D\cdot\left(\frac{\partial C}{\partial r}\right)_{r=R_1}=h\cdot\left(C^{\infty}-C|_{r=R_1}\right)$$

$$h=\frac{D_{pore}}{R_2-R_1}$$

- *Core diffusion + reaction*

$$\frac{\partial C}{\partial t}=D\cdot\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right)+Rate$$

$$Rate=\frac{\partial C}{\partial t}=A_d\cdot\exp\left(-\frac{E_d}{R\cdot T}\right)\cdot\left(C_c\cdot C_2\cdot C_w-\frac{1}{K}\cdot C_3\cdot C_5\right)$$

- A diffusion-reaction model is built based upon four consecutives steps of CO_2 adsorption: external diffusion, shell diffusion, core diffusion and chemical reaction.

CO_2 adsorption profile

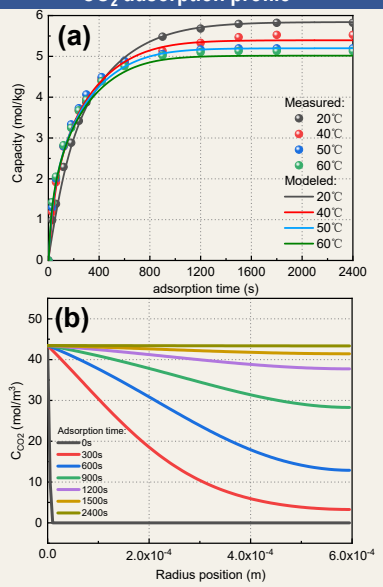


Fig 4. (a) Measured and modeled CO_2 adsorption curves at different testing temperatures; (b) CO_2 distribution inside the particle at different adsorption times

- Fig 4a shows measured and modeled CO_2 adsorption as a function of time, and Fig 4b demonstrates the CO_2 penetration profile at different adsorption times (20 ° C);
- The model reasonably captures the experimental results;
- The measured CO_2 adsorption reaches a capacity up to 5.85 mol/kg at 20 ° C, a promising result compared with other research[3].

Conclusion

- Core-shell particles displaying a satisfying CO_2 capacity up to 5.85 kg/mol are fabricated by in-air microfluidics at a productive rate of around 1 kg per hour;
- A model describing CO_2 adsorption per particle as a function of time and radial distance is proposed and validated.

References

[1] Jiang, Jieke, et al. "High-Throughput Fabrication of Size-Controlled Pickering Emulsions, Colloidosomes and Air-Coated Particles via Clog-Free Jetting of Suspensions." Advanced Materials (2023): 2208894.
[2] Visser, Claas Willem, et al. "In-air microfluidics enables rapid fabrication of emulsions, suspensions, and 3D modular (bio) materials." Science advances 4.1 (2018): eaao1175.
[3] Lin, Li, et al. "Characteristics, application and modeling of solid amine adsorbents for CO2 capture: A review." Journal of Environmental Management 325 (2023): 116438.

Contact Information

Yiwei Long
y.long@utwente.nl
University of Twente
7522 NB Enschede, Netherlands