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Mechanism of oil absorption in surface engineered sponges for wastewater treatment

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Using porous materials for absorption of fluids has been practiced for thousands of years, for e.g. water storage and release and for filtration purposes. The chemical nature of the porous material and the flow dynamics determine how absorption takes place and which fluids are preferentially absorbed. In this way, materials can be designed for various fluid separation applications. In our work, we study the effects of the pore geometry on absorption of oil into surface engineered sponges. The sponges consist of a polyurethane based fiber network and contain a porosity of ~98%. The fibers are made hydrophobic by chemical functionalization for usage in wastewater filtration and oil spillage clean-up [1]. They contain both pores in between fibers (inter-fiber pores) as well as within the fibers themselves (intra-fiber pores). We study the mechanism of the absorption process by tracking dodecane (a hydrocarbon) invasion in 3D over time using dynamic micro-CT experiments. The experiments were performed within the EXCITE network using the EMCT scanner at University of Gent Center for X-ray tomography (UGCT).

In the visual experiments, we observe an initial precursor invasion of dodecane in pores in between fibers within a few hours, without invasion of the interior of the fibers. Likely, this precursor front is driven by a density difference between water and oil, since the front moves under positive curvature (i.e. against capillarity). This indicates an initially weakly water-wet nature of the fiber surface. Quantitative volumetric measurement data, through which we fit a two-term kinetic model, show a second main front of dodecane moving into the samples on a time scale of several days. The slower main front invasion is coupled to a change in the observed fiber wettability at the pore scale from water-wet to oil-wet over time.

In order to elucidate the absorption mechanism, we conduct separate experiments using dodecane emulsified in water. We observe a gradual uniform absorption of dodecane in intra-fiber pores, on which droplets of dodecane nucleate. These droplets grow over time, partially filling the inter-fiber pores. This effect shows us that the exterior of the fibers indeed likely change to an oil-wet state due to the invasion of oil into the fibers.

This research shows not only the significance of precursor fronts in fluid absorption processes in porous media, but also that they can be caused by gravitational effects instead of capillarity [2]. The study results can be extended to porous media applications where a range of pore sizes can be expected, such as wastewater filtration, CO2 and hydrogen storage in porous reservoir rocks and paper wetting in inkjet printing.

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References

[1] Cherukupally, P., Sun, W., Wong, A. P. Y., Williams, D. R., Ozin, G. A., Bilton, A. M., & Park, C. B. (2019). Surface-engineered sponges for recovery of crude oil microdroplets from wastewater. Nature Sustainability, 3(2), 136–143. https://doi.org/10.1038/s41893-019-0446-4; [2] Constantinides, G. N., & Payatakes, A. C. (2000). Effects of Precursor Wetting Films in Immiscible Displacement Through Porous Media. Transport in Porous Media 2000 38:3, 38(3), 291–317. https://doi.org/10.1023/A:1006557114996

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