Novel synthetic nanomembranes show potential to improve industrial efficiency and sustainability

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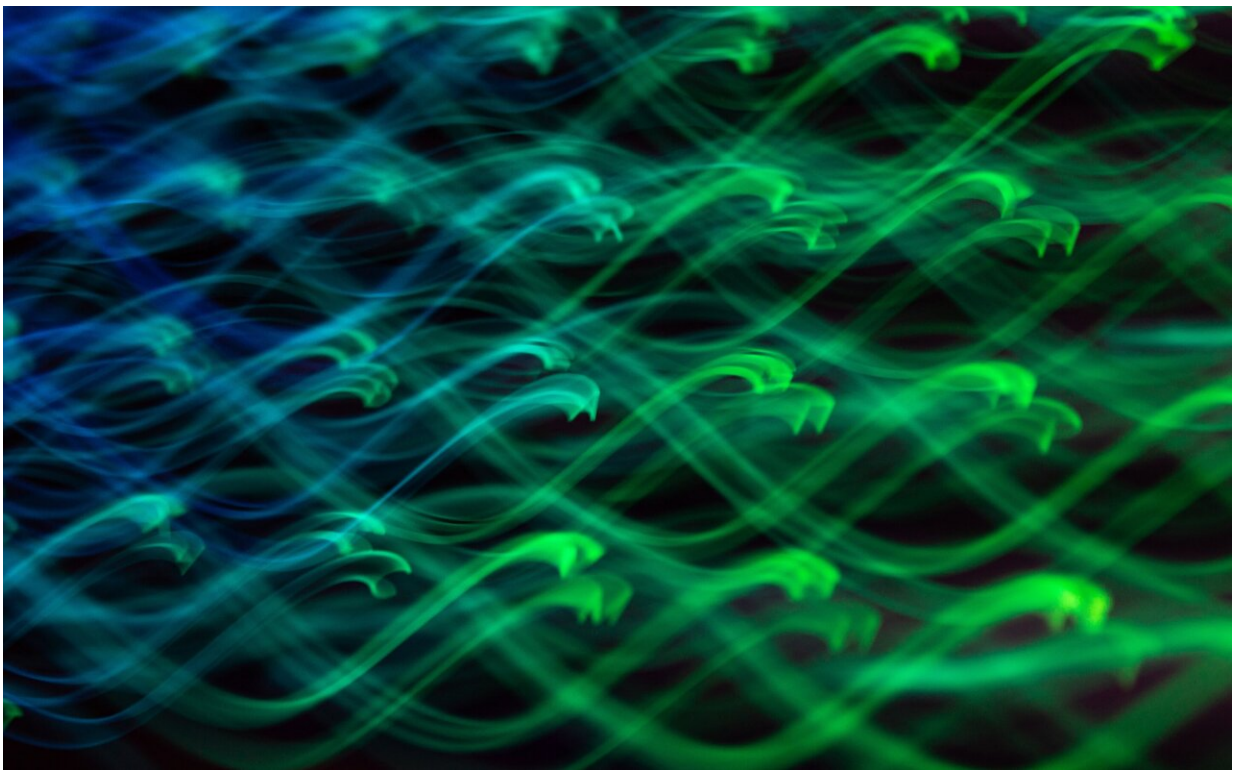

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A team from Queen Mary University of London, Imperial College London (U.K.), Northwestern University in Evanston (U.S.) and Bielefeld University (D) have produced a new breed of polymer

nanomembranes with aligned supramolecular macrocycle molecules. These new nanomembranes demonstrate properties that promise to improve the efficiency of separation processes widely used across the chemical and pharmaceutical industries.

Conventional chemical and pharmaceutical industries use 45–55% of their total energy consumption during production in molecular separations. In order to make these processes more efficient, cost-effective, environmentally friendly and therefore sustainable, these processes need to be partially or wholly replaced by novel separation strategies that make use of innovative and ground-breaking membrane technologies.

Publishing their results in the journal *Nature*, the team show that their polymer nanomembranes with aligned supramolecular macrocycles exhibit superb and extremely selective filtration properties that exceed the conventional polymer nanomembranes currently used across the chemical and pharmaceutical industries. Conventional polymer nanomembranes have a broad distribution of the pore size that lacks a controllable way to be precisely tuned.

In this new breed of polymer nanomembranes, the molecularly predefined macrocycles are aligned to provide sub-nanometer pores as a highly effective filtration gateway that separates molecules with a size difference as low as 0.2 nm. The researchers show that the arrangement, orientation and alignment of these small cavities could be realized by selectively functionalized macrocycle molecules, in which the upper rim with highly reactive groups preferentially faces upright during the crosslinking reaction. The orientated architecture of macrocycles in nanomembranes could be verified by grazing incidence wide angle X-ray scattering (GI-WAXS). This allows us for the first time to visualize the sub-nanometer macrocycle pores under high-resolution atomic force microscopy in ultrahigh vacuum, proving the concept of exploiting

different nanopore sizes using different cyclodextrin identities with Angstrom precision.

As a functional proof of concept, these nanomembranes are applied to high-value pharmaceutical separations for enriching cannabidiol (CBD) oil, exhibiting higher ethanol permeance and molecular selectivity than commercial state-of-the-art membranes. This novel concept offers feasible strategies to orientate porous materials into nanopores in membranes that can provide accurate, fast and energy-efficient molecular separations.

Dr. Zhiwei Jiang, now an EPSRC Future Leadership Fellow at Exactmer Ltd U.K., said, "The demand for CBD derived pharmaceuticals has grown rapidly, due to their great efficacy in treating depression, anxiety, and cancer. Current state-of-the-art techniques for separating CBD molecules from extracts are expensive and energy intensive. Membranes can offer a cost-effective and energy-efficient alternative, but requires accurate separations between CBD and other natural components of similar dimensions dissolved in the extract solvent. Therefore, precise control of membrane pore size is critical to this opportunity.

"In our work, the pore size of the aligned macrocycle membranes can be precisely tuned at Angstrom precision, which enabled one order of magnitude higher solvent transport and three-fold higher enrichment of CBD than commercial benchmark membranes. This extends the great potential of applying membranes in high-value industries that require accurate molecular selectivity."

"This work would definitely not have been possible without the contributions from our collaborators in the U.S. and Germany. They provided the key evidence showing the alignment of the macrocycles (GIWAXS technique from U.S.) and visualization of the aligned macrocycle pores (AFM technique from Germany). Their results are

important for verifying the molecular design and offering fundamental understandings of these membranes, and we will seek more opportunities for collaboration in future."

More information: Andrew Livingston, Aligned macrocycle pores in ultrathin films for accurate molecular sieving, *Nature* (2022). DOI: 10.1038/s41586-022-05032-1. www.nature.com/articles/s41586-022-05032-1

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