Fluid-filled pores separate materials with precision

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Credit: AI-generated image (disclaimer)

In nature, pores can continuously control how a living organism absorbs or excretes fluids, vapors and solids in response to its environment; for example, tiny holes invisible to the naked eye called stomata cover a plant's leaves and stems as gated openings through which oxygen, carbon dioxide and water vapors are transported in and out during photosynthesis and respiration. And some scientists have proposed that micropores in the tissues of the air sacs of human lungs can open or close to modulate fluid flow based on changes in air pressure or inflammation.

Just as they help control the transport of materials through pores, flow-gating mechanisms have also proved very useful for many practical applications designed by humans, such as gas and liquid separations, dialysis, or blood filtration. But conventional approaches to create synthetic "pores" have resulted in openings or gates that are fixed in geometry, often designed with only one purpose in mind. To make matters worse, these systems often get clogged during use due to accumulation of materials and fouling, and are also not energy efficient over long periods of use.

Now, a team of Harvard scientists led by Joanna Aizenberg, the Amy Smith Berylson Professor of Materials Science at Harvard School of Engineering and Applied Sciences (SEAS) and a Core Faculty member at the Wyss Institute for Biologically Inspired Engineering at Harvard University, has developed an entirely new, highly versatile mechanism for controlling passage of materials through micropores, using fluid to modulate their opening and closing. Aizenberg, who is also Professor of Chemistry and Chemical Biology in Harvard's Faculty of Arts and Sciences and Co-Director of the Kavli Institute for Bionano Science and Technology, calls the new system a "fluid-based gating mechanism." The work is reported in the March 5 issue of *Nature*.

"The ability to selectively transport or extract materials is valuable for uses such as separating components of oil, gas and wastewater, for filtering blood and fluid samples, and broadly for 3D printing and microfluidic devices," said Aizenberg. "Our new approach harnesses dynamic and responsive control over a highly sensitive and reversible gating mechanism, which we can now apply toward many diverse applications."

Aizenberg's system can separate a wide range of cargos and is extraordinarily precise due to the fact that the fluid-filled gate adjusts to accommodate filtration of each substance it encounters, even while processing a complex mixture of materials.

"The fluid used in the gate is repellent and prevents any material from sticking to it and clogging the system throughout repeated and extended use," said the study's lead author Xu Hou, a research associate at SEAS and the Wyss Institute. "To accommodate different materials and desired extractions, operators of the system simply need to adjust the pressure to influence what substances will be allowed to flow through the fluid-filled gates."

The system's dynamic control could, for example, prove especially valuable for crude oil transport, in which fuel lines frequently become clogged, leading to high costs and risk of gas accidentally escaping into the environment. Additionally, the tunable pressurization and anti-fouling properties could result in more than 50-percent energy savings compared to current methods.

"Fundamentally, it's an elegant concept. While conventional membrane technology uses all kinds of specialized materials and engineered micropores to achieve selectivity, here we simply use a fluid as a tunable valve," said co-author Alison Grinthal, a research scientist at Harvard SEAS. "Basic fluid mechanics dictate the precise extraction and output of a wide variety of liquid and gas mixtures according to easily-calculated pressure adjustments."

The next step for the team will be to increase the throughput of the system towards practical use for large-volume substance separation and commercialization.

"Joanna's fluid-based gating approach gracefully recapitulates the functions of pores seen in nature," said Donald Ingber, Founding Director of the Wyss Institute, the Judah Folkman Professor of Vascular Biology at Harvard Medical School and Boston Children's Hospital, and Professor of Bioengineering at Harvard SEAS. "This advance offers an entirely new approach with which to confront a broad range of problems in fields ranging from energy to medicine."

More information: Liquid-based gating mechanism with tunable multiphase selectivity and antifouling behaviour, *Nature*б DOI: 10.1038/nature14253

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