New active filaments mimic biology to transport nano-cargo

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Inspired by micro-scale motions of nature, a group of researchers at the Indian Institute of Technology Madras and the Institute of Mathematical Sciences, in Chennai, India, has developed a new design for transporting colloidal particles, tiny cargo suspended in substances such as fluids or gels, more rapidly than is currently possible by diffusion.

Fluid friction determines micro-scale inertia in fluid. This means, for instance, blood cells swimming within blood encounter roughly the same amount of drag that a human would experience attempting to swim through molasses.

As the group reports in *The Journal of Chemical Physics* they applied and then extended a model of active filaments that includes these frictional hydrodynamic interactions, specifically as they relate to the speed and efficiency analysis of transporting colloidal particles.

By doing so, the researchers were able to design a realizable active transport engine, significantly advancing the state of the art for studying the crucial role of momentum conservation in active systems.

"Microorganisms have developed specialized organelles, such as cilia and flagella, to overcome the challenges of, in the words of Nobel laureate [Edward] Purcell, 'life at a low Reynolds number,'" said Raj Kumar Manna, a graduate student in the Department of Physics at the Indian Institute of Technology Madras. "Recent experiments demonstrated that flagella-like 'beating' could be achieved in vitro, proving it's possible to obtain a periodic 'beating' motion without complex biological regulation."

Combining this concept of biologically independent regulation with "successful synthesis of self-propelling, inorganic particles," he also said, allowed them to create a completely artificial microscopic transport system.

The group initially set out to study designs of such transport systems via computer simulation to find designs for their "ultimate synthesis" within the laboratory.

According to Manna, most of the concepts involved in their work are more than a century old, dating from the mid-1800s with mathematician George Stokes' work on the eponymous equations for slow viscous flow. Physicist Marian Smoluchowski then used that work in the early 1900s to compute the friction, or the so-called "hydrodynamic interaction," between spherical particles moving in a viscous fluid. "We applied these techniques to the new situation of swimming within a viscous fluid," said Manna.

With these techniques they showed that it's possible to transport colloidal cargo via synthetic active filaments. "We've provided a design for a fully biocompatible motility engine that can be put to a wide variety of uses," Manna said. And such variety is offered by a surprising finding.

"Speed and efficiency aren't related within these systems," said Manna. "As an analogy, consider the energy spent by a 100-meter sprinter and a marathon runner. For a given budget of energy, it can be expended in a brief burst to achieve high speed, or more slowly to achieve long distances. This requires different design considerations, so our work provides a way of switching the behavior of our synthetic swimmer between these two modes."

The work has potential implications for procedures such as targeted drug delivery and insemination. More generally, the work is relevant for therapeutic interventions where defective motility in physiology is an issue.

"It's difficult to predict the timing for a computer design to be realized experimentally, and then go beyond clinical trials to medical use. But, if past development within this area is any guide, we expect some of these technologies to become feasible within a decade or so," Manna said.

As far as what's next for the group, Manna said, "We'd like to include increasing degrees of realism within our analysis to achieve an environment more akin to blood, look at geometries that are more like branched capillaries, explore designs for greater energy efficiency, and also collaborate more closely with experimentalists."

More information: "Colloidal transport by active filaments," Raj Kumar Manna, P.B. Sunil Kumar and Ronojoy Adhikari, *Journal of Chemical Physics* Jan. 10, 2017, DOI: 10.1063/1.49972010

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