New discovery in shear-thickening fluids such as detergents

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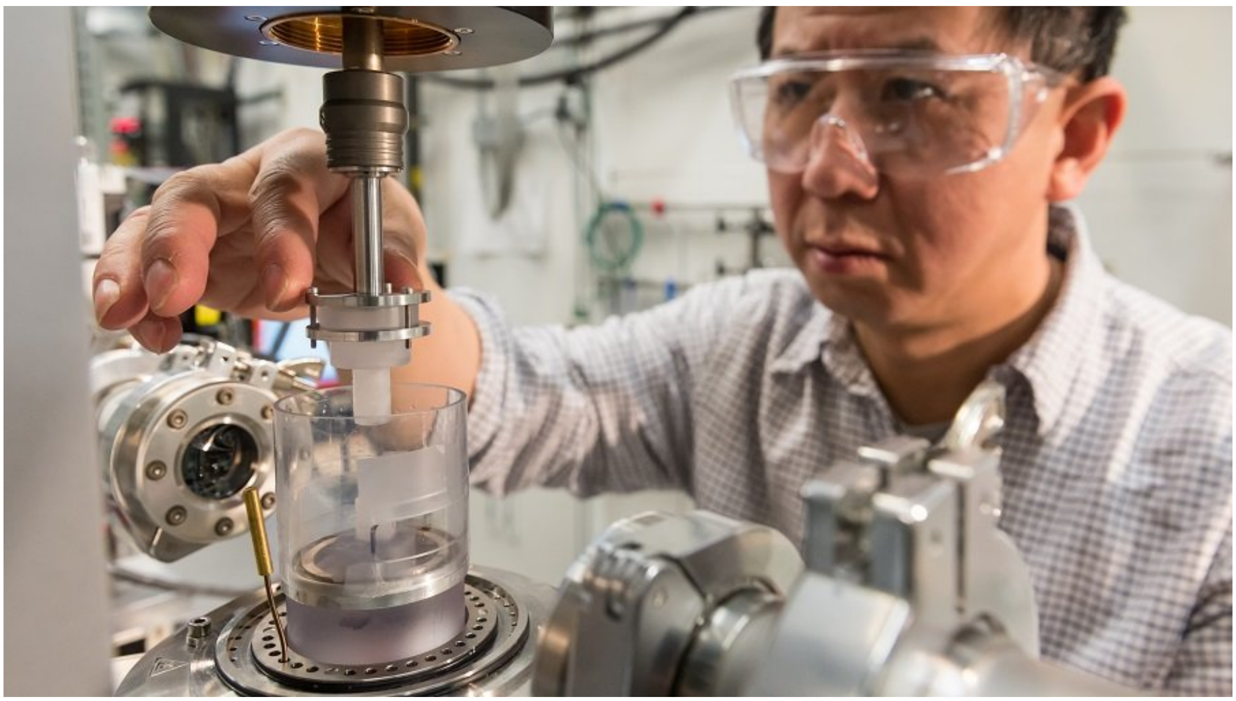

Argonne nanoscientist Xiao-Min Lin works with the shear cell device that enabled the new discovery in shear-thickening fluids. The polycarbonate cell holds the nanoparticle suspension and the mechanical response of the fluid is measured by the transducer in the rheometer above. The X-ray beam is focused on the sample from the left. Credit: Argonne National Laboratory

What do paint, dishwasher detergent, ketchup and blood have in common? All are composed of particles suspended in a carrier liquid, flow when stirred or forced, but remain thick or even gel-like at rest.

That very useful behavior in complex fluids is called shear thinning: their viscosity decreases during mixing and increases at rest. But certain fluids, when the mixing speed increases—as required in many large-scale industrial processes—can pass through the region of shear thinning and move into a region where viscosity increases dramatically, and these fluids become difficult or impossible to stir. This effect, known as shear thickening, has been under investigation for several decades as engineers sought to solve complex production problems caused by the phenomenon.

In the late 1980s, scientist Richard L. Hoffman proposed a simple model: When fluids are mixed at low speeds, the suspended particles form ordered layers that can slide easily across each other, facilitating flow. But when exposed to high speeds, the layers become disordered and stumble over one another, hindering flow; this change in the type of flow is called "order-to-disorder transition." It's a bit like a disorderly crowd, pushing and shuffling its way through a congested exit.

Other researchers were able to observe this behavior in many fluids, but not in every shear-thickening fluid. So, scientists proposed several other models to explain the shear-thickening phenomenon, but none of them address Hoffman's model.

"So the puzzle remains, how is order-to-disorder of particles related to shear-thickening behavior? Why does it happen only in certain complex fluids?" said Xiao-Min Lin, nanoscientist at the Center for Nanoscale Materials at the U.S. Department of Energy's (DOE) Argonne National Laboratory.

Now, an Argonne team of nanoscientists and physicists has unraveled this 30-year mystery by studying a shear-thickening fluid with in situ X-ray characterization.

"Combining a rheometer, which measures the viscosity of the liquid, with X-ray characterization creates a unique instrument that can understand the structure of particles when they are moving in real time," said Suresh Narayanan, another lead scientist on the project and physicist in the Time Resolved Research Group in Argonne's X-ray Science division.

The team has always suspected that particle uniformity might play a role in this phenomenon. So Jonghun Lee, the lead postdoctoral fellow on this project, synthesized highly uniform silica nanoparticles of three different diameters. Using a specific ultra-sensitive small-angle X-ray scattering (SAXS) technique at Argonne's Advanced Photon Source (APS), Lin, Narayanan and their team—now augmented with other members of the Time Resolved Research Group—measured how the nanoparticles flowed in response to an applied force in real time.

The group's effort was rewarded. The highly uniform suspensions created by the team allowed separation of the two phenomena: order-to-disorder transition and normal shear thickening. Until now, they had been indistinguishable in other experiments. The data captured in situ proved that the order-to-disorder transition discovered in the 1980s occurs in lower-stress regions and the steady shear thickening occurs in higher-stress regions. In other words, these behaviors are driven by two separate, independent mechanisms.

"But when you have non-uniform particles, these two behaviors collapse into the same region, making them indistinguishable," Lee said.

The team now seeks to understand the mechanism that really contributes to shear thickening. These studies could lead to applications in three-dimensional printing, the chemical industry and the biomedical field.

This work, titled "Unraveling the role of order-to-disorder transition in shear thickening suspensions," was published in a January issue of *Physical Review Letters*.

More information: Jonghun Lee et al. Unraveling the Role of Order-to-Disorder Transition in Shear Thickening Suspensions, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.028002

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