Images capture split personality of dense suspensions

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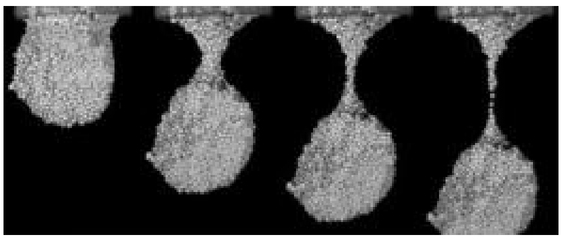

In this image, lighted from the front, water containing zirconium dioxide particles measuring 850 microns in diameter detaches from a nozzle. The suspension neck maintains a symmetric profile until the neck gradually narrows to a width of only one particle, when the liquid surrounding the particles ruptures. Credit: Marc Miskin/Heinrich Jaeger

Stir lots of small particles into water, and the resulting thick mixture appears highly viscous. When this dense suspension slips through a nozzle and forms a droplet, however, its behavior momentarily reveals a decidedly non-viscous side. University of Chicago physicists recorded this surprising behavior in laboratory experiments using high-speed photography that can capture action taking place in one hundred-thousandths of a second or less.

UChicago graduate student Marc Miskin and Heinrich Jaeger, the William J. Friedman and Alicia Townsend Friedman Professor in Physics, expected that the dense suspensions in their experiments would behave strictly like viscous liquids, which tend to flow less freely than non-viscous liquids. Viscosity certainly does matter as the particle-laden liquid begins to exit the nozzle, but not at the moment where the drop's thinning neck breaks in two.

New behavior appears to arise from feedback between the tendencies of the liquid and what the particles within the liquid can allow. "While the liquid deforms and becomes thinner and thinner at a certain spot, the particles also have to move with that liquid. They are trapped inside the liquid," Jaeger explained. As deformation continues, the particles get in each other's way.

"Oil, honey, also would form a long thread, and this thread would become thinner and break in a way characteristic of a viscous liquid," Jaeger said. "The particles in a dense suspension conspire to interact with the liquid in a way that, when it's all said and done, a neck forms that shows signs of a split personality: It thins in a non-viscous fashion, like water, all the while exhibiting a shape more resembling that of its viscous cousins."

It took Miskin and Jaeger six months to become convinced that the viscosity of the suspending liquid was a minor player in their experiments. "It is a somewhat heretical view that this viscosity should not matter," Jaeger said. "Who would have thought that?"

Miskin and Jaeger presented their results in the March 5 online early edition and the March 20 print edition of the *Proceedings of the National Academy of Sciences.*

In their experiments, Miskin and Jaeger compared a variety of pure liquids to mixtures in which particles occupy more than half the volume.

"The results indicate that what we know about drop breakup from pure liquids does not allow us to predict phenomena observed in their experiments," said Jeffrey Morris, professor of chemical engineering at City College of New York. "The most striking and interesting result is the fact that, despite these being very viscous mixtures, the viscosity plays little role in the way a drop forms."

Few studies have examined droplet formation in dense suspensions. As Morris noted, such work could greatly impact applications such as inkjet printing, combustion of slurries involving coal in oil, and the drop-by-drop deposition of cells in DNA microarrays.

Scientific Defiance

In these applications particles often are so densely packed that their behavior defies a simple scientific description, one that might only take into account average particle size and the fraction of the liquid that the particles occupy, Morris explained. The UChicago study showed that particles cause deformations and often protrude through the liquid, rendering any such description incomplete until fundamental questions about the interface between a liquid mixture and its surroundings are properly addressed.

"Miskin and Jaeger provide arguments for the importance of these protrusions in their work and suggest that the issue is of broader relevance to any flow where a particle-laden liquid has an interface with another fluid," Morris said.

Miskin and Jaeger verified their results by systematically evaluating different viscosities, particle sizes and suspending liquids, and developed a mathematical model to explain how the droplet necks evolve over time until they break apart.

One initially counter-intuitive prediction of this model was that larger particles should produce behavior resembling that in pure water without any particles. "If you want to make it behave more like a pure non-viscous liquid, you want to make the particles large," said Jaeger, who finds himself intrigued by nature's seemingly endless store of surprises.

Miskin and Jaeger indeed observed this when the particle size approached a significant fraction of the nozzle diameter, making the particles visible to the naked eye.

"You think you have a pretty good idea of what should happen, and instead there's a surprise at every corner. Honestly, finding surprises is what I love about this work," Jaeger said.

More information: "Droplet formation and scaling in dense suspensions," by Marc Z. Miskin and HeinrichM. Jaeger, *Proceedings of the National Academy of Sciences*, March 20, 2012, Vol. 109, No. 12, page 4389-4394.

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