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The Physics of Coffee Rings

For centuries, intellectuals have met at the ring-stained surfaces of coffee shops to pore over the most pressing problems of the day -- but has anyone ever pondered the coffee rings they left behind? What causes the formation of stain patterns left behind by coffee droplets on a surface? because evaporation at the solid-liquid interface of the rim occurs faster than a replenishing flow of water from the center of the droplet can replace the evaporating rim fluid. This leaves the particles on the rim high, dry and deposited.

Exploiting this competition between evaporation and replenishment is the key to controlling the process as a microtool, says Mandre. Potential applications include printing, making industrial coatings, fabricating electronics, and designing new medicines.

You might think coffee ring formation, first described quantitatively by Deegan et al in a heavily cited article, is the most widely and ritualistically performed experiment in the world, given the prevalence of caffeine in cultures. But most of us lack the scanning electron microscope and mathematical models to evaluate our stain data properly, or reach meaningful conclusions beyond "Use a coaster."

Now, Shreyas Mandre of Brown University, Ning Wu from Colorado School of Mines and L. Mahadevan and Joanna Aizenberg from Harvard University have devised a predictive model that combines laboratory studies of microscopic glass particles in solution with mathematical theories to predict the existence, thickness and length of the banded ring patterns that formed.

Their results, presented November 23 at the American Physical Society Division of Fluid Dynamics meeting in Long Beach, CA, suggest the patterned deposition of particles can be controlled by altering physical parameters such as evaporation and surface tension and perhaps one day manipulated to create small-particle tools.

"Controlling the ring deposition process would be useful for creating such things as new microphysics tools operating at a scale where pliers or other traditional tools for moving particles cannot operate," notes Mandre.

The team found that during ring deposition, a particle layer of uniform thickness is deposited if the concentration is above a certain threshold. Below that threshold the deposits form non-uniform bands. The threshold is formed because evaporation at the solid-liquid interface of the rim occurs faster than a replenishing flow of water from the center of the droplet can replace the evaporating rim fluid. This leaves the particles on the rim high, dry and deposited.

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