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International team uncovers mystery behind 'coffee ring' formation

Monash University

A new study has discovered the mystery behind 'coffee rings' and how it could advance research in blood diagnostics.

An international research team, led by Monash University, has discovered for the first time the mystery behind the formation of 'coffee rings' by examining the contact angle of droplets onto a surface, and how they dry.

The research collaboration involving Monash University and Cambridge University also developed a mathematical model that is capable of predicting when a coffee ring could be observed in hard spherical particle systems.

Professor Gil Garnier, Director of BioPRIA (Bioresource Processing Research Institute of Australia) in the Department of Chemical Engineering at Monash University, led an international team to explore how patterns formed from evaporating droplets – a phenomenon that has mystified physicists for years.

Professor Garnier said this discovery, created by Dr Michael Hertag from BioPRIA, could open up doors in the blood diagnostics arena, especially for the discovery of treatments for anaemia and other blood diseases.

Pattern formation is a common occurrence in drying colloidal liquids, such as milk, coffee, paint, aerosols, and in blood.

Most common in droplets is a ring distribution where the liquid particles have relocated to the edge, which is referred to as a coffee ring, when drying. This deposit is unfavourable in many manufacturing processes and is of fundamental interest experts in the building, medical, and engineering professions.

They concluded that the contact angles at which a droplet is placed on a wetted surface determines the prevalence of coffee angles. When the droplet is placed at a high contact angle, no coffee rings are present.

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Garnier said.

"Although successful modelling has been achieved previously, we show here for the first time that for each contact angle, there is a critical initial colloid volume fraction over which no ring-like pattern will be formed.

"Essentially, the lower the contact angle, the higher likelihood that ring profiles will be found."

When a droplet is placed on a surface, it quickly reaches an apparent equilibrium position that can, for small droplets, be defined solely by contact angle and radius.

The rate of evaporation and the variation of mass fluidity on the drop's surface is dependent on many factors, including the vapor pressure of the fluid, the geometry of the droplet's surface as well as the velocity and partial pressure of the surrounding atmosphere.

Drying experiments were conducted by placing a 6μL droplet of solution onto a substrate with an Eppendorf pipette. The droplet was left to dry in a humidity and temperature controlled room held at 23°C and 50 per cent relative humidity.

"We showed that the presence or absence of a coffee ring can be solely predicted by the initial volume fraction of particles in a suspension and the contact angle formed by the suspension on the surface of interest," Dr Garnier said.

"Using this finding, we were then able to calculate a model to predict coffee ring formation from contact angles using a number of liquid droplets.

"This modelling technique and its resulting insights are new powerful tools to optimise manufacturing and diagnostic techniques."

This work was funded by the Australian Research Council with Haemokinesis and an Australian Government Research Training Program Scholarship.

Professor Gil Garnier from BioPRIA and Monash University's Department of Chemical Engineering led the study titled: 'Predicting coffee ring formation upon drying in droplets of particle suspensions'. Co-authors of the study are Michael Hertaeg (BioPRIA and Chemical Engineering), Clare Rees-Zimmermann and Alexander Routh (University of Cambridge), and Rico Tabor (School of Chemistry, Monash University).

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