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EDITED AND REVIEWED BY
Alex Hansen,
Norwegian University of Science and Technology, Norway

*CORRESPONDENCE
Carole Planchette,
carole.planchette@tugraz.at

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Editorial: Physics of droplets

Carole Planchette[1]*, Grazia Lamanna[2] and Kuo-Long Pan[3]

[1]Institute of Fluid Mechanics and Heat Transfer, Graz University of Technology, Graz, Austria, [2]Institute of Aerospace Thermodynamics, University of Stuttgart, Stuttgart, Germany, [3]Department of Mechanical Engineering, National Taiwan University, Taipei, Taiwan

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Editorial on the Research Topic
Physics of droplets

Droplets are frequently encountered in our daily lives [1], and have long played a prominent role in industries [2]. Processes such as atomization and sprays have become so familiar that one might overlook the complexity of the underlying physics and the numerous unresolved questions that persist. This Research Topic, comprised of original research articles, aims to advance fundamental knowledge on the physics of droplets and facilitate their widespread and effective application.

Under the influence of various types of forces, such as inertial force, viscous shear, and interfacial tensions, as well as of surrounding conditions, such as geometrical constraints, temperature field, electric and magnetic forces, droplets (or more generally multiphase flows) experience a multitude of deformations, including elongation. Liquid masses stretched beyond a certain aspect ratio become unstable. The reduction of surface area and flow driven by capillary pressure gradients lead to their fragmentation into smaller droplets. The well-known Plateau-Rayleigh instability is just one of many mechanisms of droplet formation. The resulting droplets open the possibilities to modify heat, mass, and momentum interactions with the environment.

The paper by Joksimovic et al., which focuses on spray cooling of solid substrates, perfectly illustrates both the apparent familiarity of the process due to its widespread use and the challenges with optimizing it beyond empirical knowledge. By adding white lubricant to distilled water, cooling efficacy can be strongly improved. High-speed movies provides valuable insights into the fundamental phenomena responsible for these improvements. At lower lubricants concentrations, heat exchange is primarily enhanced through the increased viscosity. For intermediate concentrations, the deposition of lubricant crystals onto the substrate improves the wetting conditions, and thus the contact between liquid and solid phases. Finally, at higher concentrations, surfactants stabilize liquid sheets found between adjacent bubbles, preventing vapor channels to percolate and thus, the undesired Leidenfrost effect. In the context of diabatic multiphase flows, where hot liquid droplets are dispersed within another liquid, the evaporation of the continuous phase can have profound consequences. Cunningham and Frost presents a critical scenario, namely, the melt-coolant interaction-driven explosion, which can potentially take place in nuclear reactors. Such an explosion occurs when a triggering event initiates the coherent propagation of interactions among dispersed melt fragments through the coolant. To mitigate such risks, it is imperative to comprehend how individual melt droplets disintegrate and the ensuing impacts on temperature, pressure, and velocity fields within the coolant and its vapor. By combining high-speed photography and flash radiography, the authors unravel the existence of two fundamentally different processes. At low velocities, thermal effects drive droplet disintegration, while at higher velocities, hydrodynamic instabilities, particularly Rayleigh-Taylor and Kelvin-Helmholtz, govern the drop's disintegration. At intermediate velocities, both processes coexist, resulting in a more complex fragmentation.

Beyond previous example, the advancement of measurement technologies has driven the acquisition of new information in increasingly dynamic and extreme environments. Techniques continue to evolve with a constantly improving temporal and spatial resolution, enabling theoretical models and simulations to be probed and further developed. Within this Research Topic, two noteworthy experimental methodologies are presented, promising significant contributions to the scientific community.

In Ulrich et al., the capabilities of two-color laser-induced fluorescence for droplet thermometry are showcased. By employing fluorescein disodium and sulforhodamine 101, the authors achieve a sensitive signal ratio between one temperature-dependent and one temperature independent fluorophore. This approach allows for monitoring the cooling process of evaporating droplets within the distance separating them from the nozzle.

An alternative experimental technique to analyse quantitatively the behaviour of evaporating droplets was presented by Steinhausen et al. The authors employed laser-induced thermal acoustics (LITA) to investigate the mixing behaviour in the wake of an evaporating droplet injected into a supercritical atmosphere in combination with planar spontaneous Raman scattering. By applying an advection controlled mixing assumption, it was possible to determine for the first time the concentration-temperature field in the droplet wake. The analysis indicates a classical two-phase evaporation process with evaporative cooling of the droplet, so that the subsequent mixing of fluid vapour and ambient gas remains also subcritical in the direct vicinity of the droplet.

Concurrently with these advancements, computational progress has opened complementary avenues to explore parameters that may not be easily varied experimentally [3, 4]. This is exemplified by Roa et al. which presents Computational Fluid Dynamics simulations of single oil droplets dispersed in water and flowing through a membrane with a variable contact angle at various flow rates. The membrane geometry is derived from the CT-scanned porous structure of borosilicate glass, and thus very realistic. The OpenFoam interFlow solver, coupled with isoAdvector, is employed to resolve the multiphase flow within this intricate geometry. While state-of-the-art experiments may not precisely control the contact angle of the dispersed phase with the membrane, numerical simulations advantageously treat it as a freely adjustable parameter. Furthermore, these simulations offer detailed insights into either the retention (filtration, lipophilic membrane) or the breakup (emulsification, lipophobic membrane) of the droplet. The findings will contribute to the optimization of operating conditions, enabling membrane-based processes to become more energy-efficient.

In addition to practical applications, numerical simulations play a crucial role in unraveling fundamental physics. In Roa et al., demonstrate how turbulent conditions developing in the continuous phase influence the oscillations of droplets dispersed within it. While solving individual oscillation modes theoretically derived from weakly viscous linear theory is feasible, the complexity increases significantly when considering a large number of modes and accounting for their coupling with the surrounding flow. The authors address this challenge through numerical simulations, revealing that, after a transient regime, the deformation level of the droplet surface reaches a saturation level. This saturation level determines the stored surface energy and is set by the surrounding turbulence. Under the studied conditions, the droplet relaxation is found to be governed by capillary forces, an expected result that supports the validity of this work.

The variety of the physical problems discussed in this Research Topic provides a good overview of the current progress in experimental and numerical methods, aimed at advancing knowledge of multiphase systems under extreme conditions.

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Conflict of interest

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