

Droplet Impact Dynamics on Functional Substrates for Contact Time Reduction, Particle Capture, and Droplet Generation

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ABSTRACT

This thesis explores droplet impact across engineered surfaces to achieve reduced contact time, controlled particle pickup, and tunable generation of particle-laden droplets. First, the dynamics of droplets impacting superhydrophobic meshes (SHMs) and hybrid mesh-surface configurations are examined to overcome the conventional capillary-inertial limit on contact time. It is revealed through experiments that partial penetration through mesh pores reduces the effective spreading diameter and shortens contact time by more than 20%. When a superhydrophobic surface is introduced beneath the mesh, jet elongation is restricted, producing a pancake-bouncing mode that reduces contact time by over 50% without fragmentation.

Building on these dynamics, the controlled jet formed during droplet impact on an SHM is then investigated as a tool for precise particle capture. High-speed imaging and systematic variation of droplet energy, mesh and particle-bed distance, particle type, and liquid rheology demonstrate that the recoilable jet enables tunable pickup of micro- and nanoscale particles over more than three orders of magnitude (~10–2000 particles per droplet). The method succeeds even in highly viscous (58 mPa·s) and low-surface-tension (33.67 mN/m) media, allowing selective extraction of trace particle quantities that are otherwise difficult to collect.

The final part of the thesis presents a scalable approach for generating tunable particle-suspended droplets on lubricant-infused surfaces (LIS). During retraction, the stretched liquid column becomes unstable and eventually breaks, which allows the droplet to separate cleanly without getting pinned to the surface. This breakup process makes it possible to form droplets ranging from a few nanoliters to microliter volumes, and it remains effective even when the liquid contains a high concentration of particles-up to nearly 30% (w/w) with particles of about 5 μm in size. Use of a nonfluorinated soot-based LIS enhances environmental and economic viability. Collectively, the findings advance droplet manipulation strategies for applications in materials synthesis, biomedical assays, drug discovery, and droplet-based microreactor technologies.