COALESCENCE OF SPREADING DROPLETS ON A WETTABLE SUBSTRATE

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Research on drop coalescence has focused on the case of two spherical drops or bubbles floating in fluid [1]. Coalescence also occurs, however, between drops located on solid substrates. The coalescence process on substrates consists of two stages: an initial rapid growth of a meniscus bridge between the droplets, and a slow rearrangement of the combined droplet shape from elliptical to more circular at longer times. Previous work on the coalescence of sessile drops has focused on the latter stage [2-4], but the dynamics of the first stage are crucial to applications where drops impinge, condense, or spread on substrates. For example, in spray painting and spray coating the material properties of the resulting solid coating depend sensitively on the extent of coalescence before fluid motion is hindered by other physical processes (e.g., solidification due to cooling or solvent evaporation). Similarly, liquid and chemical imbibition on plant foliage is directly affected by drop coalescence, since drops drain off by gravity upon reaching a critical weight. At smaller length scales, a primary objective of microfluidic devices is to study chemical or biological kinetics in small volumes by rapidly mixing two droplets with different reactants; several techniques have been developed to maneuver sessile droplets toward one another so that they may coalesce. Despite the broad range of phenomena affected by drop coalescence on substrates, the influence of geometric and material parameters on the coalescence behavior on substrates has remained obscure.

In this work, we investigate the early-time coalescence dynamics of thin viscous droplets spreading due to surface tension on a flat, wettable substrate. We show experimentally and numerically that in the limit where the initial heights of the droplets (just prior to coalescence) are small compared to their radii ($h_o \ll R_o$) the time-dependent width $d_m(t)$ of the meniscus bridge between the two merging droplets is governed by a simple scaling law, $d_m \sim \left(t\ h_o^3/R_o^2\right)^{1/2}$. This scaling is consistent with an elementary mass conservation model in the context of the lubrication approximation, wherein the meniscus growth is limited by the viscously hindered flux from the droplets. Surprisingly, details about the curvature of the meniscus bridge are not necessary to predict the meniscus growth, despite the putative role of the meniscus curvature in driving the coalescence process. This suggests that thin-film coalescence might be similarly calculable in other more complex geometries (e.g., multiple droplets or droplets on cylindrical fibers). Although many systems of interest involve equilibrium contact angles larger than those studied here, the results for the limiting case of infinitesimal angles should establish a lower bound for the coalescence rate of droplets with larger contact angles.

References

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