ABSTRACT

Title of Thesis: IMPACT OF POLYMERIC DROPS ON DROPS AND FILMS OF A DIFFERENT BUT MISCIBLE POLYMER

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The fluid mechanics of a liquid drop impacting on another stationery (or spreading) liquid drop or on a liquid film (of thickness comparable, or smaller, or larger than the impacting drop) has attracted significant attention over the past several years. Such problems represent interesting deviations from the more widely studied problems of liquid drops impacting on solid surfaces having different wettabilities with respect to the impacting drops. These deviations stem from the fact that the resting liquid (in the form of the drop or the film) itself undergoes deformation on account of the drop impact and can significantly affect the overall combined drop-drop or drop-film dynamics. The problem becomes even more intriguing depending on the rheology of the drop(s) and the film as well as the (im)miscibility of the impacting drop with the underlying drop or the film. Interestingly, the majority of such drop-impact-on-drop or drop-impact-on-film studies have considered Newtonian drop(s) and films, with little attention to polymeric drop(s) and films.

This thesis aims to bridge that void by studying, using Direct Numerical Simulation (DNS) based computational methods, the impact-driven dynamics of one polymeric drop on another (different but miscible) polymeric drop or film. As specific examples, we consider two separate problems. In the first problem, we consider the impact of a PMMA (poly-methyl methacrylate) drop on a resting PVAc (polyvinyl acetate) drop as well as the impact of a PVAc drop on a resting PMMA drop. In the second problem, we consider the impact of a PMMA drop on a PVAc film as well as the impact of a PVAc drop on a PMMA film.

For the first problem, the wettability of the resting drop (on the resting surface), the Weber number of the impacting drop, the relative surface tension values of the two polymeric liquids (PVAc and PMMA), and the miscibility (or how fast the two liquids mix) dictate the overall dynamics. PVAc has a large wettability on silicon (considered as the underlying solid substrate); as a result, during the problem of the PMMA drop impacting on the PVAc drop, the PVAc drop spreads significantly and the slow mixing of the two liquids ensures that the PMMA drop spreads as a thin film on top of the PVAc film (formed as the PVAc drop spreads quickly on silicon). Depending on the Weber number, such a scenario leads to the formation of transient liquid films (of multitudes of shapes) with stratified layers of PMMA (on top) and PVAc (on bottom) liquids. On the other hand, for the case of the PVAc drop impacting on the PMMA drop, a combination of the weaker spreading of the PMMA drop on silicon and the "engulfing" of the PMMA drop by the PVAc drop (stemming from the PVAc having a smaller surface tension than PMMA) ensures that the impacting PVAc drop covers the entire PMMA drop and itself interacts with the substrate giving rise to highly intriguing transient and stratified multi-polymeric liquid-liquid structures (such as core-shell structure with PMMA core and PVAc shell). For both these cases, we thoroughly discuss the dynamics by studying the velocity field, the concentration profiles (characterizing the mixing), the progression of the mixing front, and the capillary waves (resulting from the impact-driven imposition of the disturbance).

In the second problem, we consider a drop of the PMMA (PVAc) impacting on a film of the PVAc (PMMA). In addition to the factors dictating the previous problem, the film thickness (considered to be either identical or smaller than the drop diameter) also governs the overall droplet-impact-driven dynamics. Here, the impact, being on the film, the dynamics is governed by the formation of crown (signifying the pre-splashing stage) and a deep cavity (the depth of which is dictated by the film thickness) on the resting film. In addition to quantifying these facets, we further quantify the problem by studying the velocity and the concentration fields, the capillary waves, and the progression of the mixing front. For the PMMA drop impacting on the thin film, a noticeable effect is the quick thinning of the PMMA drop on the PVAc film (or the impact-driven cavity formed on the PVAc film), which gives rise to a situation similar to the previous study (development of transient multi-polymeric-liquid structures with stratified polymeric liquid layers). For the case of the PVAc drop impacting on the PMMA film, the PVAc liquid "engulfs" the deforming PMMA film, and this in turn, reduces the depth of the cavity formed, the extent of thinning, and the amplitude of the generated capillary waves. All these fascinating phenomena get captured through the detailed DNS results that are provided.

The specific problems considered in this thesis have been motivated by the situations often experienced during the droplet-based 3D printing processes (e.g., Aerosol jet printing or inkjet printing). In such printing applications, it is commonplace to find one polymeric drop interacting with an already deposited polymeric drop or a polymeric film (e.g., through the co-deposition of multiple materials during multi-material printing). The scientific background for explaining these specific scenarios routinely encountered in 3D printing problems, unfortunately, has been very limited. Our study aims to fill this gap. Also, the prospect of rapidly solidifying these polymeric systems (via methods such as in-situ curing) can enable us to visualize the formation of solidified multi-polymeric structures of different shapes (by rapidly solidifying the different transient multi-polymeric-liquid structures described above). Specifically, both PMMA and PVAc are polymers well-known to be curable using in-situ ultraviolet curing, thereby establishing the case where the present thesis also raises the potential of developing PMMA-PVAc multi-polymeric solid structures of various shapes and morphologies.