Simultaneous PIV and interface tracking applied to drops impacting and moving through a confining orifice

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Examples of liquid/liquid interfacial interaction with a solid constriction are ubiquitous in many natural processes as well as industrial applications such as CO₂ sequestration. When the liquid/liquid interface makes contact with the solid rock surface, the contact line motion becomes challenging to observe experimentally or simulate numerically (Snoeijer and Andreotti (2006), Herminghaus et al. (2008)). In this paper, we demonstrate an automated interface tracking method applied to planar PIV results for water/glycerin drops impacting and moving through a sharp-edged hydrophilic orifice in presence of silicone oil. Using this method, we demonstrate the effect of orifice-to-drop diameter ratio (d/D) on the time resolved velocity and vorticity fields and the corresponding deformation of the drop. For a sharp-edged hydrophilic plate with strong wettability, we also examine contact line motion along the plate.

Experimental Setup and Methods

The experimental setup includes an acrylic tank (255 mm x 255 mm x 280 mm) filled with silicone oil to a height of 160 mm. A hydrophilic glass plate (equilibrium contact angle = 55°) with a sharp-edged circular orifice at its center was suspended horizontally inside the tank at 120 mm below the free surface. Drops, released above and axisymmetric to the orifice, encountered the plate after reaching terminal speed (U). The drop-orifice plane of symmetry was illuminated using a Nd:YLF laser with pulse energy 30 mJ and pulse frequency 1 kHz, and the flow was imaged using a Fastcam Ultima APX camera (1024x1024 resolution, frame rate 1 kHz). The two liquids were refractive index matched to avoid optical distortion in PIV. A very small quantity of Rhodamine B was added to the drop fluid to distinguish the drop from the surrounding oil.

In order to identify and track the drop interface, raw PIV images were processed in MATLAB. To eliminate scattering from the plate, an image without the drop was subtracted from each test image. Then median and standard deviation filters were applied, followed by a “canny” edge detection scheme. Finally, boundaries were ‘closed’ through a series of iterative morphological operations, and the location of the orifice plate was masked.

Results and Conclusions

In general, depending on drop Bond number (Bo) and d/D, an impacting drop either may be captured above the plate or penetrate through the orifice (see Bordoloi and Longmire, 2014). When the orifice edges are sharp, the drop fluid contacts the leading orifice edge immediately after impact so that the final outcome is influenced by the wettability of the plate surface. A sample raw PIV image and the corresponding velocity vectors superposed with the tracked interface and vorticity contours vorticity are shown in Figs. 1(a) and (b) respectively. Immediately after impact, a part of the drop fluid flattens above the plate and the trailing contact line spreads across the upper plate surface. The remaining drop with the leading contact line penetrates through the orifice.

![PIV image with drop](image)

Fig. 1 (a) A raw PIV image with drop (Bo = 5, d/D = 0.62) impacting a sharp-edged hydrophilic orifice and (b) Contours of dimensionless vorticity superposed with velocity vectors (reference vector 1.00/i in blue) and the drop boundary.

The tracking method applied to the entire sequence allows time-wise characterization of the deforming drop and contact line motion. For example in Fig. 1(b), the deflection of the trailing interface causes circulation and generates vorticity near the interface.

The propagation of drop contact line above and across the orifice plate is also tracked and the effect of d/D on the spreading rate is examined. Initially, the underlying film of oil and the contact line are driven outward across the plate at a rapid rate. After the film drains, however, the contact lines are driven only by wettability so that the spreading rate decreases by an order of magnitude. For a larger d/D = 0.6, the drop fluid penetrates the orifice and limits the extent of spreading across the plate compared to d/D=0.4.

References