Experimental Analysis and 3D-Visualization of Oscillating Hollow-Conical Liquid Sheets in Quiescent Air

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Abstract

This work deals with the investigation on propagating hollow-conical liquid sheets formed by a pressure swirl atomizer during the process of sheet disintegration in quiescent air. The liquid emerges from the nozzle as a hollow conical sheet soon becoming unstable and disintegrating due to different mechanisms, i.e. Kelvin-Helmholtz-instability and turbulence. The frequent application of swirl atomizers in a wide range of industrial and medical applications requires a better understanding of the sheet break-up process. Measurements and visualization of details on the drop formation process are needed as a basis to control and improve the spraying processes based on sheet breakup. As opposed to the non-invasive image based spray analysis performed by several authors, an invasive experimental approach based on polymer optical wave-guides was employed here. Experimental investigations with this measuring technique were presented in the past [1], when multiple optical fibers were arranged in parallel in a shape of a comb and positioned in the main flow direction of the moving sheet. In the present work, eight of these sensors, consisting of 55 fibers each, were positioned equidistantly along the perimeter of the hyperbolical sheet and in same distance from the nozzle orifice. This arrangement allows for measurement of sheet displacements in 2D+t, interpolating the data in the area between the eight sensors. The distance between the sensors and the nozzle orifice was graduated in small steps in order to collect sheet characteristics on a large part of the whole sheet. This setup allows for reading of various sheet characteristics along the spray cone perimeter, such as the dominating oscillation frequencies and the corresponding amplitudes, in lateral as well as in longitudinal direction. A data post-processing, with an active contour approach allows for automatic signal extraction, analysis and visualization. Additional processing of the captured light information was undertaken to estimate the dominant frequency-bands of the oscillating liquid sheet, by means of Wavelet-analyses. Combining the experimental results of the 2D measurements, by means of 3D reconstruction, leads to a visualization of the sheet behavior in 3D. All experiments were performed with a water-glycerol-mixture, at constant viscosity of $\eta L = 32$ mPas and a surface tension of $\sigma = 68$ mN/m. The liquid pressure was graduated in steps between $0.05 < \Delta p < 0.16$ MPa ($0.5 < \Delta p < 1.6$ bar). Linear instability models for thinning viscous and inviscid liquid sheets as available from the literature and are compared with experimental data. The presence of the lateral waves on the hollow conical sheet was analyzed by considering the three-dimensional effects as described in [2]. The coexistence of longitudinal and lateral waves at lower We-numbers was confirmed, leading to the conclusion that the emerging pattern of the sheet deformation has to be considered.

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Key Words: Swirl Atomizer, Sheet Disintegration

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