Experimental Examination of the Liquid Sheet Disintegration Process Using Combined Photography and Fiber Based Measuring Techniques

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Abstract

The behavior of liquid sheets in ambient air is examined with a combination of conventional photography methods and fiber based sensor techniques. This combination allows a detailed insight into the characteristics of the processes ahead of the drop formation process, such as sheet velocity, oscillation frequency and amplitude, spray angle and sheet break-up length. The proximate evaluation of the raw image data was performed using contour tracking and image filtering techniques, enabling a fully automated evaluation of whole data sets.

Introduction

The effectiveness of atomization process depends significantly on the control of the drop formation. Despite extended research on this topic, there is no universally valid description of the mechanism of sheet break-up. This work deals with the analysis of multiphase flows during the process of sheet disintegration at Hollow Cone Nozzles (**HCN**). The liquid emerges from the nozzle as a 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 the drop formation process in detail are needed as a basis to understand and eventually improve the spraying processes based on sheet breakup.

Materials and Methods

The experimental setup consists of the measuring units and the atomization system, which allows the operation at different liquid pressures and temperatures, as well as of different nozzles. Using water-glycerol mixtures, the entire viscosity range relevant for swirl-atomizers was covered (1-50 mPas). The atomization pressure was graduated in steps between $0.3 < \Delta p < 2.0$ bar. The different nozzle geometries are obtained by fitting different nozzle parts from a kit. The dimensions of inlet ports, swirl chamber and outlet geometry was changed independently, the examined orifice diameters chosen in the range between 8 and 15 mm. A combination of conventional photography and fiber based sensor techniques was used to characterize the sheet disintegration process. The photographic imaging was performed using the backlighting technique with a battery of 1800 high power LEDs forming a flat and homogeneous light source out of focus. The images were acquired using a PCO-Pixelfly with a spatial resolution of 1 MPixel at an exposure time of 10 µs resulting in very sharp raw images with high contrast values (Figure 1a). The raw images were extracted and evaluated in order to elaborate the spray angle and the sheet break-up length as shown in Figure 1b. The second measuring system is based on the fiber technology. Here, the measuring technique exploits the Fresnel effect on the plane fiber end to detect differences in the refractive index. As in past investigations [1, 2], multiple fibers were bundled to a 1-dimensional array able to read phase-changes along a line (Figure 2a and 2b). In order to record sheet oscillations in longitudinal (flow direction) as well as in lateral direction four sensors were located in circumferential direction. The combination of fiber-sensor data and photographic images offers an almost complete set of sheet characteristics, which enables comparison with existing sheet break-up theories [3, 4 and 5].

Results and Discussion

The investigations have shown different characteristics for the growth of aerodynamic waves as well as for the spray angles and break-up lengths depending on the operating conditions and nozzle geometry. Within the range examined, the frequency analysis of the sheet oscillation shows dominating oscillation frequencies at all flow conditions within the range of $50 < f < 1000$ Hz. With growing distance to the nozzle orifice, the dominating frequency remains constant. With increasing liquid viscosity, the dominance of one particular frequency also increases, which probably results in a closer drop size distribution. The coexistence of longitudinal and lateral waves at lower We-numbers was shown experimentally and a quantification of these frequencies was success-

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fully performed. The presence of oscillations in lateral direction of low viscous sheets has also been stated by Mehring at al [5]. However, these kind of waves where measured here on viscous sheets with the fiber sensor and were confirmed with photographical images, although the origin of these waves as well as their influence on the resulting drop sizes is still not clear. The sheet thickness was estimated with the aid of the obtained oscillation and velocity data considering the mass flow conservation. The decrease in sheet thickness due to its spread along divergent streamlines, as well as caused by the growth of wave amplitudes is found to be significant. The drops formed from the sheet as predicted based on mass balances lead to different sizes compared to the assumption of a constant sheet thickness as made by Dombrowski at al [3].

Acknowledgement

The authors thank the german research association "Deuschte Forschungsgemeinschaft (DFG)" for their financial support of this project.

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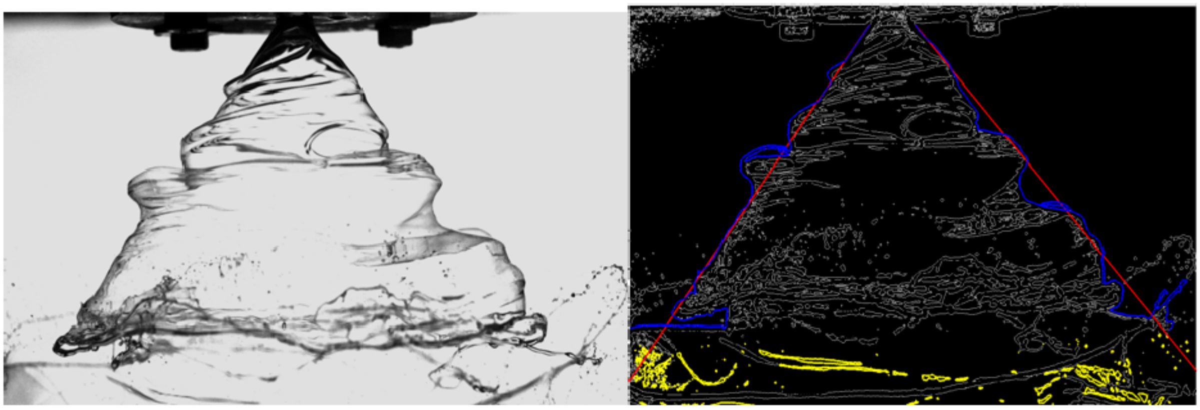

Figure 1. a: raw image of sheet atomization at 42 mPas and 0.8 bar emerging from a HCN with an orifice diameter of 15 mm , b: same image after applying filters showing the spray angle and the break –up region

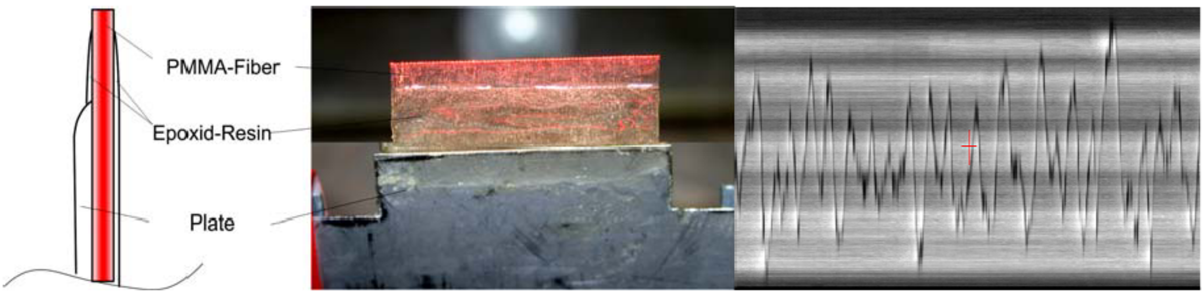

Figure 2. a: 1-D fiber array consisting 250 µm PMMA-fibers b: recorded sheet displacement over time at constant distance from the nozzle orifice