Experimental Investigation of Droplet-Droplet Interactions

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Abstract
Shadowgraphy is an established imaging measurement method, allowing in particular to determine droplet velocity and diameter distributions. One advantage of Shadowgraphy compared to other non-intrusive measurement methods is that it is able to directly observe collision and coalescence processes. As in many practical two-phase flows the expected collision probability is moderate, and since the acquisition frequency of the Shadowgraphy system is limited as well, this measurement method must be optimized for the investigation of droplet-droplet interactions. In this work it is shown that Shadowgraphy can be indeed applied for a quantitative investigation of collision and coalescence. For this purpose the software has been considerably improved, allowing an automatic analysis of the measurement results. The software (DaVis 7.2 from LaVision) has been extended with the help of its built-in macro language. The resulting experimental procedure has been tested by measurements in a two-phase wind tunnel. Corresponding results are presently compared with that of theoretical predictions.

Introduction

Collision rates of water droplets in a turbulent flow is a key property to understand many practical issues, e.g., for numerical predictions of rain soiling and warm rain initiation in clouds. Both theoretical [1] and numerical [2] investigations are available for this purpose in the literature, but there is a lack of reliable experimental data for droplet-droplet interactions in turbulent flows with controlled conditions. Developing a suitable experimental database is the purpose of the present work, allowing finally model testing and improvement by comparison between theory and measurements.

Experimental Methods

The existing two-phase wind tunnel at the University of Magdeburg was used for the experimental measurements described here. The transparent measurement section of the wind tunnel is 360×450×400 mm. The velocity of the air flow is varied between 3 and 25 m/s by prescribing a constant rotation speed of the fan, with the help of the frequency regulator of the wind tunnel. Turbulence intensity is measured to be around 10 %, since the spray head and the injection of the water droplets generate relatively high velocity fluctuations. Two cases are considered, Case 1 being associated to small droplets (mean size of 10 μm) and Case 2 to large droplets (mean size of 750 μm). The spray is generated in Case 1 by a twin-fluid full cone pneumatic atomizing nozzle (166.208.16.12 from Lechler), applying an air gauge pressure of 1.2 bar. For Case 2, a flat cone pressure atomizer (type CJM from Delavan) is employed. To keep the inlet values constant, a PID-controller was programmed as well. In this way it is possible to create a steady water volume flow rate, leading to a constant droplet diameter during the whole acquisition time. The typically obtained droplet size distribution can be described in Case 1 by a probability density function as a two-parameter log-normal distribution,

$$y = f(d|\mu,\sigma) = \frac{1}{d\sigma\sqrt{2\pi}} \exp\left[-\frac{(ln(d)-\mu)^2}{2\sigma^2}\right], \tag{1}$$

with the shape and scale parameters $\sigma = 0.72$ and $\mu = 2.41$ respectively, i.e., the mean and standard deviation of the normal distribution [3]. In Case 2, a two-peak distribution is obtained (peaks at 300 μm and 1100 μm) leading to a mean droplet size 730 μm, with droplet diameters up to 2200 μm.

Shadowgraphy, applied here for the investigation of the droplet-droplet interactions is an imaging measurement method, relying typically on a PIV-camera, a far-field microscope, and a pulsed laser with a fluorescence disc. The camera and the illumination lie on the same optical axis. As the droplets are illuminated from behind, their shadow image is recorded on the camera and the diameter of the droplets can be obtained by means of the previously

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calibrated μm/pix value [4, 5]. As the expected collision rate is usually moderate in dispersed flows, and since the recording frequency of the camera is limited to 10 Hz, measurements with meaningful statistics must be carried out for a long period of time at a chosen position. The collision events are then identified automatically and their number is divided through the total number of evaluated droplets in order to get the probability of collisions.

Results and Discussion

The applied evaluation algorithm is based on droplet shape recognition and discriminates collision events from aerodynamic droplet deformation, which is an essential issue when considering larger droplet diameters. Therefore, the first measurements were carried out with the help of a flat cone pressure atomizer and the improved experimental method was tested by means of the larger droplets (Case 2). A suitable theoretical prediction can be found in the literature [6], where the collision probability is given as:

$$N = \frac{1}{2} n^2 d^2 \left(\frac{16\pi \overline{u_p^2}}{3} \right)^{1/2}, \tag{2}$$

yielding a probability of 0.41% for the present conditions, where N is the number of collisions per unit volume and unit time, n is the number of droplets per unit volume, with a diameter d and the variance of the droplet velocities in the mean flow direction $\overline{u_p}$. After post-processing the experimental results of Shadowgraphy, a local collision probability of 0.39% has been measured in the center of the spray cone (Fig.1, left). A single collision event is shown in Fig.1 (right) as an example. The comparison between theoretical prediction and measured value is very good for the conditions of Case 2. The influence of the main parameters will now be checked by varying them separately. Furthermore, small droplet diameters (Case 1) will also be considered to investigate rain formation in clouds.

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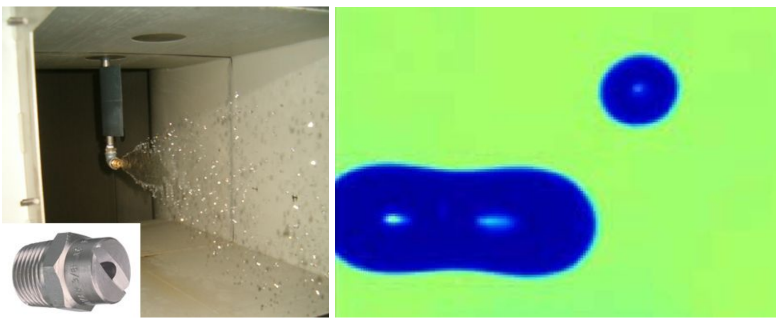

Figure 1. Spray head installed in the two-phase wind tunnel at the University of Magdeburg (left) and example of a single collision event (right) for Case 2.