Mitteilung

Fachgruppe: Allgemeine Strömungstechnik

Calculation of the three-point contact angle for water droplets on a surface from a rearward droplet observation

Rupert Anschütz, Andreas Westhoff and Konstantin Niehaus
German Aerospace Center (DLR), Institute of Aerodynamics and Flow Technology, Göttingen, Germany, Rupert.Anschuetz@dlr.de

Droplet condensation on cooled surfaces is a phenomenon that occurs in a variety of technical applications and in nature. For example, the condensation of droplets on camera lenses leads to aberration [1] or droplets on surfaces can increase the effectiveness of heat exchangers [2]. With the objective to determine the impact of droplet formation on optical properties or on the heat transfer an accurate detection of droplet distributions on surfaces is of utmost importance. Therefore, we have been developing a non-invasive measurement and evaluation method to characterise droplet ensembles on a surface by means of diameter and contact angle. In this conference contribution, we focus on the evaluation method to determine the three-phase contact angle from microscope images using a tray-tracing algorithm.

An important aspect for understanding droplet condensation is the quantification of mass transfer rates and the resulting water mass on the surface. For the determination of the local water mass on a surface, we have developed an automated measurement method [3] to determine the droplet diameters that can be used to calculate the water mass assuming a constant contact angle. However, when droplets grow or shrink during condensation or evaporation, the contact angle often changes while the radius remains almost constant as shown by Parisse et al.[4]. Therefore, a method which allows to measure the contact angle and the droplet diameter simultaneously is highly desirable. However, it is difficult to detect the three-phase contact point from a lateral perspective due to the small droplet size and limited lines of sight due to obstruction by neighbouring droplets at a high droplet density. Therefore, a direct measurement of the contact angle is often not possible. To overcome this issue, we propose a non-invasive experimental method for the detection of droplets involving the simulation of the contact angle.

Figure 1b shows a photo of the experimental set-up for droplet investigation. The set-up consists of a cooling plate, two cameras equipped with far field microscopes to record the droplets on the cooling plate, and a ring light to illuminate the droplets from the flipside as illustrated in figure 1b. The rear camera is parallel oriented to the cooling plate in order to observe the contact area of the droplets, while the lateral camera observes the contact angle.

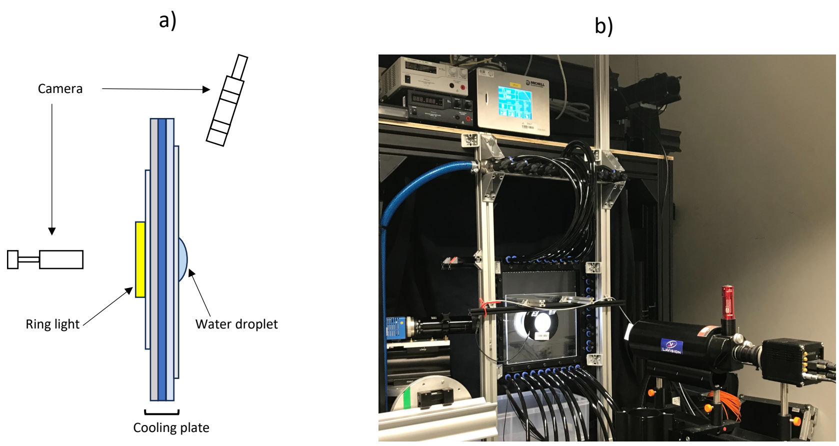

Figure 1: (a) Sketch of the cooling plate with the positions of the camera with the far-field microscopes. (b) Photo of the experimental set-up (front view).

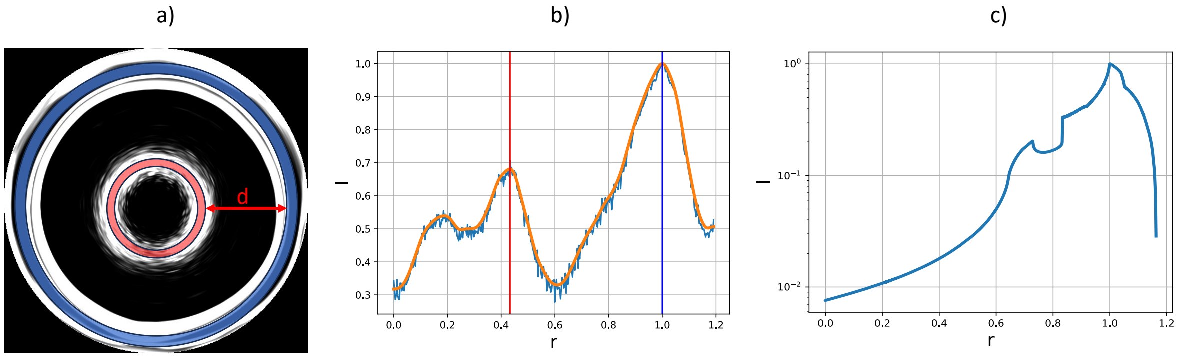

Figure 2: (a) Images showing the inner (red) and outer (blue) reflection ring of a single droplet. (b) Averaged intensity I as a function of the normalised radius r with centre position r=0. (c) Model of the averaged intensity I as a function of the normalised radius r with the same radius and contact angle as the droplet in figure 2b).

Figure 2a depicts a sample result of a single droplet recorded by the rear camera with a diameter of $400\mu m$ after image postprocessing. The image reveals the inner (red) and the outer (blue) reflection rings. Here, the outer ring is the result of enhanced light reflections at the boundary of the droplet, while the internal reflection depends on the geometric properties of the droplet. In addition, the radius of the outer ring represents the radius of the droplet. The distance of these two rings dependents on the contact angle of the droplet. Figure 2b shows the corresponding over four axis averaged radial intensity distribution, where the centre of the droplet is $r = 0$. The plot depicts two local maxima representing the centre radius of the inner and outer ring, respectively. In the following, the distance between these maxima is $d = r_o - r_i$.
By means of the distance d and the droplet radius r_o we can calculate the contagt angle. Therefore, we implemented a geometric ray-tracing algorithm to calculate the light intensity of the droplet as a function of the radius, assuming the shape of the droplet is a perfect sphere. Initially, the possible angles of incidence are checked for the first reflection point on the airside surface of the droplet. This is calculated for points at a regular distance along the radius on the airside surface of the droplet. Each of the possible incident rays are traced through the droplet until it hits the liquid-gas surface. Further, the intensity loss due to transmission at each reflection point is taken into account, as well as the loss through the different layers of the cooling plate. To obtain the intensity distribution on the rear side of the cooling plate, the sum of the intensities is calculated. Figure 2c shows the intensity as the function of the radius r from the ray-tracing calculations where the y-axis is scaled logarithmically. Based on an ensemble of these calculations for the here investigated parameter range a functional relation $\alpha = f(d, \theta_C)$ is formalised to determine the contact angle alpha by means of the droplet diameter r_o and the distance d.
At the workshop we will present the experimental set-up, introduce the ray-tracing algorithm, the method to calculate the contact angle and a discussion of the accuracy of this evaluation procedure as well as the limitations of this method.

References

[1] F. Secci und A. Ceccarelli, „On failures of RGB cameras and their effects in autonomous driving applications“, *2020 IEEE 31st Int. Symp. Softw. Reliab. Eng. ISSRE*, S. 13–24, Okt. 2020, doi: 10.1109/ISSRE5003.2020.00011.

[2] H. Nguyen und H. S. Ahn, „A comprehensive review on micro/nanoscale surface modification techniques for heat transfer enhancement in heat exchanger“, *Int. J. Heat Mass Transf.*, Bd. 178, S. 121601, Okt. 2021, doi: 10.1016/j.ijheatmasstransfer.2021.121601.

[3] K. A. Niehaus, M.-C. Volk, A. Westhoff, und C. Wagner, „Evaluation of three measurement techniques for water-vapor mass transfer in case of droplet condensation“, in *8th Thermal and Fluids Engineering Conference, TFEC 2023*, College Park, MD, USA: ASTFE Digital Library, März 2023, S. 1525–1536. doi: 10.1615/TFEC2023.the.046304.

[4] F. Parisse und C. Allain, „Shape Changes of Colloidal Suspension Droplets during Drying“, *J. Phys. II*, Bd. 6, Nr. 7, S. 1111–1119, Juli 1996, doi: 10.1051/jp2:1996119.