Experimental and numerical investigation of particle-droplet-substrate interaction

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Introduction

The impact of water droplets (0.68 – 1.66 mm diameter, velocity between 1-2 m/s) on a non-fixed spherical particle (polymethyl methacrylate (PMMA), diameter 1.55 mm) is studied experimentally and numerically. The particle is positioned on a plane PMMA substrate. The impact of the water droplets (Weber number between 13 and 94) leads to different impact scenarios ranging between lift-off of the particle-droplet system, wetting of the particle as well as deposition of the droplet on the particle. Furthermore, the influence of the eccentricity is studied on the impact phenomena. For the numerical modelling, an immersed boundary method is applied to study the impact on the free moving particle which is implemented as an immersed body whereas the droplet is modelled with a Volume-of-Fluid method (VoF).

Material and methods

The droplet impact on a plane PMMA plate was studied experimentally by using a syringe to produce water droplets between 0.68 and 1.66 diameter. The impact velocity on the PMMA particle (diameter 1.55) which was positioned on the PMMA plate was varied by using different heights. The impact was observed with two high speed cameras used to extract the positions of sphere and droplet as well as the contact angles and length of contact lines. The eccentricity of the impact was detected as well. Due to approx. 50 experiments for one droplet size, the influence of the eccentricity was studied as well. Details of the set-up, postprocessing of the data are described in detail in [1]. For the modelling of the process, a coupled Volume-of Fluid (VoF) method to describe the two-phase flow and an Immersed Boundary Method (IBM) to calculate the movement of the particle is used. The IB method is implemented in OpenFOAM® as a library allowing to use arbitrary OpenFOAM® solvers (here: interFoam for the VoF-method). Details of the method can be found in [2],[3].

Results and Discussion

The impact can be characterized by a set of dimensionless parameters, namely the ratio of droplet d_d and particle d_p diameter $\Phi = \frac{d_d}{d_p}$ and the Weber number $We = \frac{\rho_d v_d^2 d_d}{\sigma_d}$ which is based on the droplet velocity v_d just before the impact, the surface tension σ_d and the density of the droplet ρ_d. Fig. 1 shows the plot of the dimensionless diameter ratio as a function of the Weber number. Four different regimes A-D with a complete lift-off of the particle and droplet (A and B), an attachment of the droplet to the particle (C) and a complete wetting of the particle can be observed and categorized according to the dimensionless numbers. A lift-off can be observed for moderate Weber numbers and a droplet-particle ratio around 1.

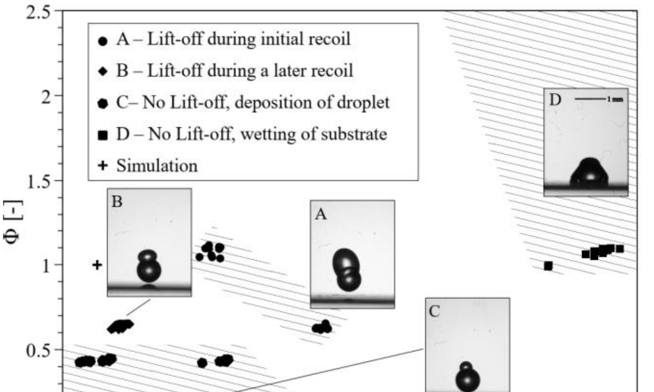

Figure 1. Dimensionless ratio droplet and particle diameter $\Phi = \frac{d_d}{d_p}$ as a function of the Weber number *We* for experimental and numerical results

Fig. 2 shows a comparison of the experimental and numerical results for a lift-off scenario for a droplet-particle ratio Φ =0.91 and a Weber number *We*=13 for different times. The numerical model can predict the scenario of the lift-off (see comparison in Fig. 1) as well as the temporal behaviour of the impact and the lift-off.

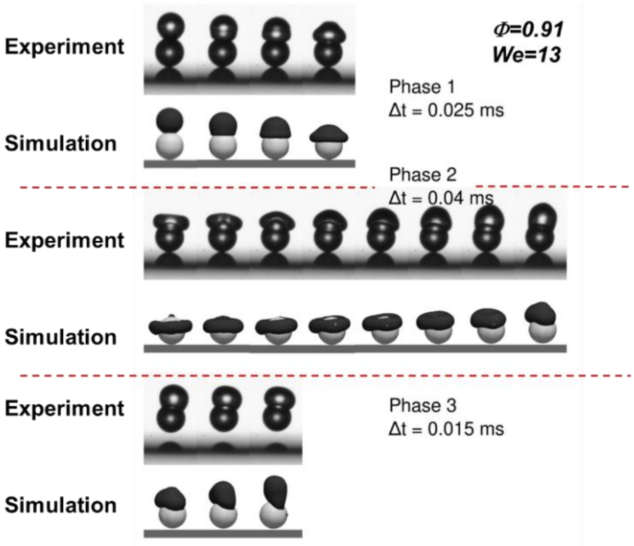

Figure 2. Comparison of experimental (top) and experimental (bottom line) results for different times for *We*=13 and $\Phi = 0.91$

Nomenclature

d_d	Droplet diameter [m]
d_p	Particle diameter [m]
v_d	Droplet velocity [m/s]
We	Weber number [-]
ρ_d	Droplet density [kg/m³]
σ	Surface tension [N/m]
Φ	Ratio of droplet and particle diameter [-]

References

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