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Numerical Investigation of Droplet Impact on Metallic Meshes

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Abstract

The present paper focuses on the numerical studies of droplets impinging onto metallic meshes, aiming to provide further insight, identify and quantify droplet impact characteristics that are difficult to be evaluated experimentally. For this purpose, an enhanced Volume-Of-Fluid (VOF) based numerical simulation framework, previously developed in the general context of OpenFOAM CFD Toolbox is utilised. In more detail, initially, validation studies of droplets impacting onto solid surfaces, previously reported in the literature are presented, for relatively high We numbers, in comparison to the ones tested in the past with the same model. Then, specific in-house experimental droplet impacts on metallic meshes are reproduced numerically, with satisfactory degree of agreement. Finally, the numerical model allows us to probe/study parameters difficult to reach experimentally, and perform a series of parametric numerical investigations in order to isolate, identify and quantify the effect of fundamental controlling parameters, such as the fluid viscosity, surface tension as well as the metallic surface wettability characteristics, on the resulting droplet impact dynamics.

Introduction

Droplet impact on solid surfaces has been the subject of numerous experimental, theoretical and numerical studies in the past decades, with numerous experiments conducted as well as numerical methods developed and applied for predicting and understanding their behaviour. However, there are areas where still the existing knowledge is limited. One of these areas is the droplet impact on porous surfaces. The present investigation specifically focuses on droplets that are impacting on suspended metallic meshes. The proposed metallic meshes represent "porous media" analogs, where both the porous characteristics as well as the permeability of the fluid can be controlled and quantified. In more detail, a previously developed VOF-based numerical simulation framework by Georgoulas et al. (2015) and Vontas et al. (2016) is further validated and applied for the numerical reproduction of in-house experiments of droplet impact on suspended metallic meshes.

Numerical Method

The utilised numerical simulation code constitutes an improved/enhanced version of the original VOF-based solver that is distributed with the official distribution of OpenFOAM CFD Toolbox ®. Particularly, the proposed model accounts for spurious current reduction and also uses Kistler's Dynamic Contact Angle (DCA) treatment, to accurately predict the apparent DCAs during the droplet spreading and recoiling stages. More details in the implementation and validation of the proposed enhancements/improvements, can be found in Georgoulas et al. (2015) and Vontas et al. (2016).

Validation of the Numerical Method

Further validation of the proposed, enhanced VOF-based numerical model, that was previously checked against experiments of droplets impacting on surfaces with variable wettability characteristics, is initially conducted here for higher We number impacts against literature available experiments. A qualitative as well as a quantitative comparison is presented in Fig. 1, for one of the selected validation cases, indicatively. The contact diameter of the droplet with respect to time is plotted for 3D and 2D-axisymmetric simulations in conjunction with the corresponding experimental measurements reported in the work of Sikalo et al. (2005). Snapshots of the experimental high speed images in comparison with the corresponding numerical simulation results are also included. As it can be observed the utilised numerical simulation framework successfully predicts both the advancing as well as the recoiling stages of the considered droplet impact experiment.

Droplet Impact on Metallic Meshes

As mentioned previously, the main aim of the present paper is to numerically investigate droplet impacts on suspended metallic meshes. For this purpose, in-house experiments of droplet impact on metallic meshes, have been numerically reproduced. The proposed metallic mesh structures have a pore

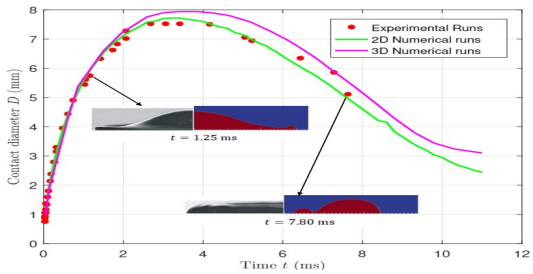

Figure 1: Comparison of experimental runs by Sikalo et al. (2005), with the numerical reproduction of the proposed phenomenon using the enhanced VOF-based numerical simulation framework, for both 2D-axisymmetric and 3D simulations.

and wire diameter of 400 μm and 220 μm respectively, while the working fluid is distilled water at 20°C. For the mesh generation, the snappyHexMesh utility was used. In Fig. 2, the experimental and the corresponding numerical computational domain as well as the constructed computational mesh are depicted for the 400 μm case.

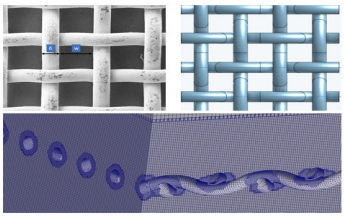

Figure 2: Top: top view of an actual metallic mesh structure,pore and wire diameter of 400 μm from the laboratory experiments and its corresponding 3D CAD reproduction. Bottom: detail of the constructed computational mesh

The main experimental parameters, that have been used as a reference case for the overall numerical simulations of the present investigation are summarized in Table 1. Some indicative results from the numerical reproduction of the proposed case are shown in comparison with the corresponding experimental run in Figure 3, for two different mesh sizes.

Table 1: Reference case characteristics

Case	D_0 (mm)	U_0 ($\mathrm{m\,s^{-1}}$)	We	Re	θ_a (°)	θ_r (°)
A	2.70	1.85	126	4953	110	93

As it can be observed the 4 million cells case, shows a relatively good agreement with the experiments. Therefore, this mesh density was selected in order to conduct a series of parametric numerical experiments aiming to identify and quantify the effect of fundamental controlling parameters, in the volume of water that is retained on the metallic mesh structure with respect to time, during the droplet impact phenomenon. In more detail, in the proposed parametric numerical simulations, the effects of fluid viscosity, surface tension as well as wettability, on the dimensionless liquid volume (that remains attached to the metallic mesh structure) with

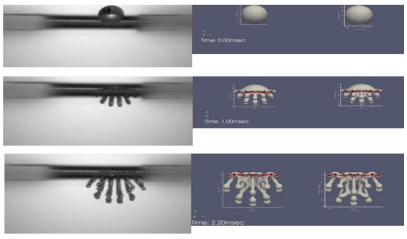

Figure 3: Reference case: comparison of experimental and numerical results for two different mesh sizes (31.9 and 4 million cells, respectively.

respect to time, are isolated, identified and quantified. Fig. 4 depicts indicatively the effect of fluid viscosity, from the proposed parametric analysis.

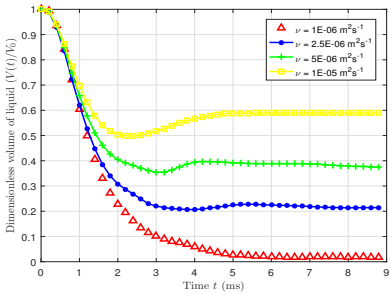

Figure 4: Effect of kinematic viscosity on the resulting fluid volume that is retained on the metallic mesh with respect to time.

Conclusions

From the overall post-processing and analysis of the numerical simulations it can be concluded that the proposed numerical simulation framework can be utilised to give further insight into the analysis of the experimental data, since it can quantify details that are difficult to be evaluated from the experimental measurements.

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