Drop impact onto porous surface: scale effects

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Introduction

In this work the isothermal impact of drop on a porous surface is investigated. The study of drop impact, spreading and rupture, has an evident relevance in different fields. The outcome of a drop impact can be well predicted for smooth surfaces, but the effects of surface porosity and roughness on droplet impact are not well understood.
Roisman et al. [1] developed a model describing the different regimes of splashing thresholds by analysing two substrate characteristics: roughness and porosity. They proposed an experimental map obtained by different combinations of Reynolds, Weber numbers and surface roughness, concluding that the two most significant parameters influencing the prompt splash-position are Weber number and a ratio given by two geometrical characteristics linked to roughness. They found more difficulties in describing the experimental results about impact onto porous substrates due to irregular morphologies of the target, and the addition of several parameters to the problem, such as substrate porosity and pore diameter. They observed that in this case deposition without splash is more probable. This outcome may be due to a rapid, partial penetration of

the drop into the target but further work is needed to clarify this phenomenon.
This research aims at defining a map of regimes to describe the different kind of outcomes given by drop impact, for different combinations of pore dimension, impact velocity, drop radius, liquid surface tension and viscosity. Pore dimension is defined as the mean pore diameter. In order to identify the different regions of the transition map, it was chosen to make reference to the dynamic (p_d) and capillary (p_c) pressures

$$p_d = \frac{1}{2}\rho v_i^2 \quad p_c = \frac{\sigma}{D_{pore}} \tag{1}$$

where ρ is the density of the droplet, v_i the impact velocity, σ the surface tension and D_{pore} the mean pore diameter. The flow characteristics are mainly described thanks to the dimensionless Weber and Reynolds number [2]

$$We = \frac{\rho d v_i^2}{\sigma} \quad Re = \frac{\rho d v_i}{\mu} \tag{2}$$

where d is the droplet diameter and μ the liquid viscosity. In defining a dimensionless number given by the ratio between drop diameter and pore diameter, $\frac{d}{D_{pore}}$, the purpose is to observe if at the same value of this number, the same outcome in terms of impact outcome results. By clarifying the roles that the dimensionless diameter has on the impact outcome, without avoiding the effects of impact velocity and liquid characteristics, a more thorough prediction of drop impact outcome on complex surface could be achievable.

Material and methods

The experiments carried out in this study consisted of drop of water impacting on stainless steel meshes purchased from Plastock, with a mean pore size ranging from 25 to 425 µm and a thickness ranging from 25 to 125 µm
A combination of different surface materials and liquids is necessary in order to study their respective influence. In order to avoid elasticity due to the thin thickness of the meshes, it was necessary to carefully attach the meshes to a flat surface. The optical setup included a Photron Fastcam SA4 high speed camera (with a resolution of 1024x800 pixels), and angled at 61°. The test area was illuminated using a custom-built high-speed LED light source, synchronised to the high-speed camera.
The drops were generated using a 21 gauge needle, with inner diameter 514 µm and outer diameter 819 µm.

Results and Discussion

By reporting a transition map with respect to $\frac{p_c}{p_d}$ and the Weber number, the experiments are aimed at outlining the different drop impact regimes. At lower values of impact velocity ($p_c > p_d$) deposition occurs, otherwise, increasing the value of impact velocity ($p_d > p_c$) an imbibition is obtained. Kumar et al. [3] pointed out that the overall imbibition is influenced both by the material of the porous media and capillary and showed that increasing drop size brings to a slower imbibition. The third region describes the splashing threshold, reached by a further increase of impact velocity. The general trends of impact outcomes given by the present work are shown in the video sequences below.

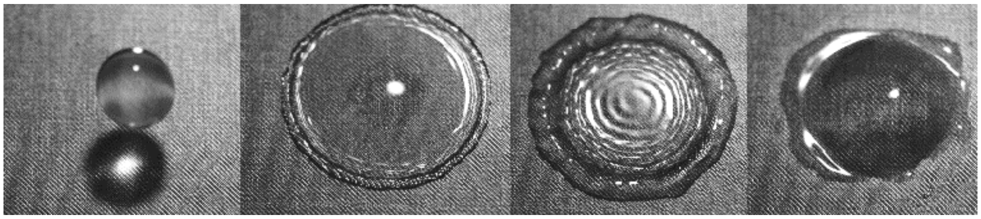

Figure 1. Deposition outcome: $d = 3{,}02\ mm, v_i = 2{,}04\ m/s\ , D_{pore} = 25\mu m$

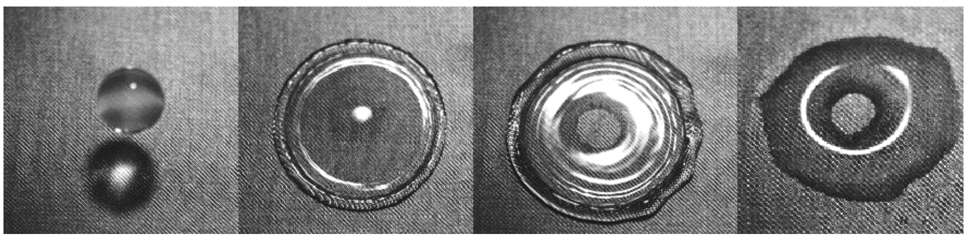

Figure 2. Partial imbibition outcome: $d = 3{,}01\ mm, v_i = 2{,}04\ m/s\ , D_{pore} = 25\mu m$ → Same impact parameters, different outcome.

Nomenclature

p_d Dynamic pressure [Pa]
p_c Capillary pressure [Pa]
σ Surface tension [N/m]
ρ Liquid density [kg/m^3]
D_{pore} Pore diameter [m]
d Droplet diameter [m]
v_i Impact velocity [m s^{-1}]
We Weber number
Re Reynolds number

References

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