Optimal splashing

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Summary: drops, instability, atomization, experiment, passive flow control, scaling theory.

Extended Abstract

Introduction

The splashing process that occurs when a droplet impacts on a solid surface with sufficient speed was studied. The objective was to determine the conditions at which the **splashing** is **optimal,** i.e. as a means of atomizing the primary drop into many small secondary drops. Splashing has been studied extensively in literature (e.g. [1]-[4] and references therein) but most studies focus on splashing process, rather than the splashing products.
The splashing performance is characterised by (i) the splashing efficiency and (ii) the size of secondary droplets. The splashing efficiency is defined as the ratio of cumulative mass of secondary droplets to the mass of original drops, and is thus dimensionless.

Method

The splashing process was studied experimentally by a **liquid jet** impinging on a rotating disk (figure 1). Atomization efficiency and secondary droplet size distribution were measured using a photographic method. Measurements were analyzed in a dimensionless form suggested by scaling theory ([2], [3]). As independent parameters we adopt the dimensionless impact velocity, u, which is defined in terms of the droplet Reynolds and Weber number (that take the droplet diameter as length scale):

$$u = (\mathrm{Re}\, We^2)^{1/8} ,$$

and the dimensionless surface roughness,

$$R_a^* = \frac{R_a}{d_0}$$

which is the ratio of the rms surface roughness height and the diameter of the impinging drop (or liquid jet). Other independent dimensionless parameters can be demonstrated to be of little importance.

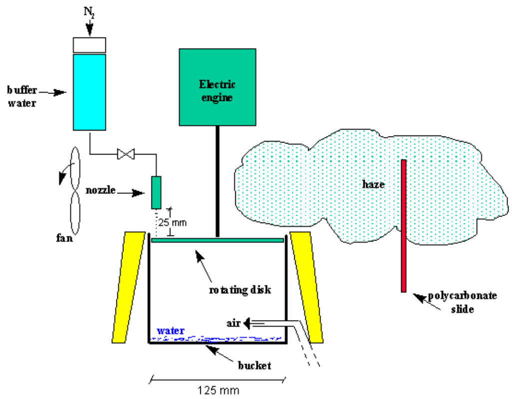

Figure 1. Experimental set-up for measurement of splashing efficiency and droplet size. The liquid velocity is controlled by nitrogen pressure. The liquid jet impacts on the rotating surface. Splashing atomizes part of the liquid; the aerosol is removed by a gently blowing fan. Non-splashed liquid is removed from the surface by the spinning motion of the disk and is collected in the stationary bucket. Samples of the atomized droplets are collected on a surface (polycarbonate). Splashing efficiency is measured from the mass of the non-splashed film.

Results

- Splashing performance is characterised by splashing efficiency and secondary droplet diameter distribution. These quantities were measured and found to collapse in scalings that depend only on dimensionless impact velocity and dimensionless roughness (figure 2, 3). This scaling resembles the two parameters in the Moody diagram for friction factor in long pipes.
- To obtain a high splashing efficiency (exceeding 75%) a dimensionless impact velocity of at least 30 is needed; above this value there is little improvement (figure 4).
- To obtain as small as possible secondary droplets, a very high dimensionless impact velocity is needed. There is some evidence to suggest that d/d0 tends to 0 for u tend to infinity.
- Roughening the surface was shown to lower the threshold velocity above which splashing occurs, in agreement with literature.

Conclusion

- Optimal splashing is obtained by normal impact of a droplet on a rough, non-wetting surface at the highest possible impact velocity.
- The analysis demonstrated that viscous-, inertia- and surface tension forces are important in splashing the process, as well as details of the solid surface (roughness topography, wettability, presence of liquid film).

References

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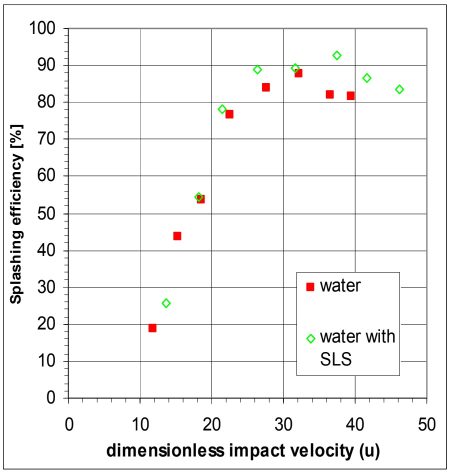

Figure 2. Splashing efficiency as function of dimensionless impact velocity. Red symbols, water (surface tension $\sigma = 72$ mN/m); green symbols, water containing sodium lauryl sulfate (SLS) ($\sigma = 40$ mN/m). Rough surface $R_a^* = 0.31 \pm 0.06$. Jet diameter d_0 = 0.2 mm.

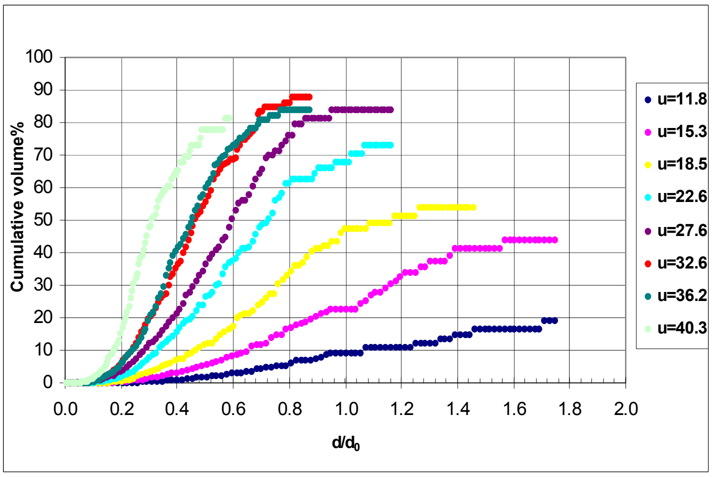

Figure 3. Effect of impact velocity on atomization efficiency (vertical axis) and secondary droplet size (horizontal axis), as function of dimensionless impact velocity, *u*.Water jet (d_0= 0.2 mm) impacting normal on rough surface ($R_a^* = 0.31 \pm 0.06$).
Optimal splashing corresponds to the top left point of this graph. Increasing u number is seen to correspond to a tedency towards this optimal splashing point.

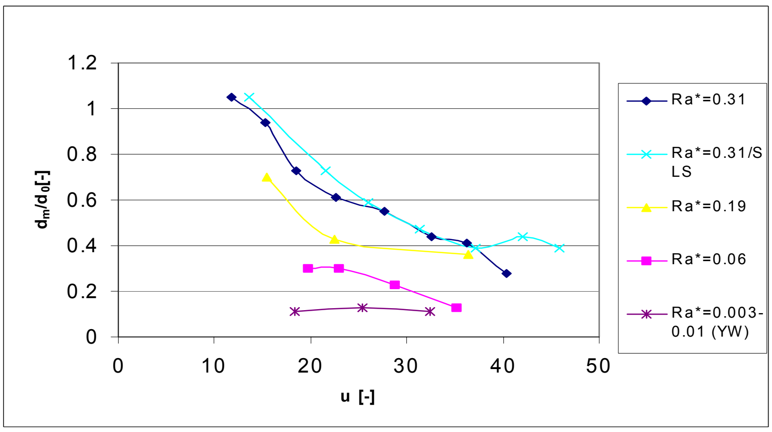

Figure 4. Volume median diameter of secondary droplets, dm, made dimensionless with d0 versus dimensionless impact velocity. Curves denote fixed dimensionless surface roughness. Present data is for liquid jet with water or SLS for different values of the dimensionless roughness parameter. For comparison, data for droplets obtained by Yarin and Weis [3] is shown.