BREAKUP OF POLYMER SOLUTION DROP IMPACTING A SMALL TARGET

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Summary The effects of high molecular additives on the splashing of liquid drops impacting a small target were studied experimentally. A splashing threshold criterion has been constructed.

MOTIVATION

The collision of a liquid drop with a small target is a model for the collision of a drop with a hydrophobic plane surface when there is no viscous friction between the liquid and the surface. The hydrodynamic features of the collision, which are usually hidden by the viscous effects, can be observed in "a pure view" [1]. Such type of experiment is particularly convenient to study the effects of polymeric additives on the impacting drop splashing in great details.

EXPERIMENTAL PROCEDURE AND RESULTS

The collisions of drops of dilute polymer solutions with a small disk-like target were investigated experimentally. Aqueous solutions of polyethylene oxide of molecular mass 4 millions at weight concentration 1, 10, 100 p.p.m. (PEO-1, PEO-10, PEO-100) were used. The velocities of the impacting drops were 3.8 m/s, and their diameters before impact were 2.7 mm. The target was a stainless steel disk of diameter 4 mm. The collision was visualized by high-speed videorecording. As in the case of pure water [1], a lamella in the shape of a circular film with a relatively thick rim was formed upon impact. At first it increased in diameter, and then, it retracted with formation of radially directed secondary jets (Figure 1). The lamella dynamics results from the competition between the inertial, surface and probably elastic forces (in the case of polymeric liquid) that control the rim motion. No essential difference in the maximum lamella diameters and their retraction rates was observed between the water and the polymeric fluids [2]. But the polymeric additives essentially changed the features of the lamella retraction. Secondary jets, which broke up into separate secondary droplets with water, were transformed into thinning filaments, connecting the lamella to the secondary droplets with polymeric fluids (Figure 1). Depending on the polymer concentration two situations were realized: either the filaments broke up, and the secondary droplets were ejected – *i.e.* splashing happened (PEO-1); or the filaments did not release the secondary droplets, until the latter coalesced back with the main drop – splashing did not happen (PEO-100).

SPLASHING THRESHOLD

A transition criterion for drop impact with or without splashing [2] was constructed. The analysis is based on the comparison between the time at which the filament breaks and the time that is necessary for both the retraction of the filament with attached droplet and the coalescence of the droplet with the main drop. If the first time is smaller than the second one then the filament breaks and the droplet is ejected. In the opposite case the droplet coalesces with the main drop before the filament rupture. It was found that the influential factors are the dynamic conditions of impact and the elasticity of the liquid. The splashing threshold is written as:

$$(\rho\, d_i^3/(\gamma\theta^2))\cdot We_i^{\chi}=K\,, \tag{1}$$

where ρ is the liquid density, d_i is the diameter of a drop before impact, γ is the liquid surface tension, θ is the fluid relaxation time [3], $We_i=\rho\, v_i^2 d_i/\gamma$ is the impact Weber number, v_i is the velocity of impact; χ = 3/8, K = 1140 at the splashing threshold. Relation (1) predicts, that if its left-hand part is larger than 1140, the drop breaks up into separate droplets, and it does not occur in the opposite case. For the particular cases of collisions of drops of PEO-1, PEO-10 and PEO-100 solutions displayed in Figure 1, the left-hand part of relation (1) receives the values 20637, 872 and 44, accordingly. The drop of PEO-1 breaks up into separate droplets. The case of PEO-10 is the closest one to the critical situation (among the three values, 872 is closest to the critical parameter K=1140). Although few droplets are separated, the main part of the liquid saved its continuity. With PEO-100 drops, no liquid losses are observed. Relation (1) can therefore be proposed as an empirical expression of splashing threshold for impact on plane surface: the parameters χ and K can be determined experimentally.

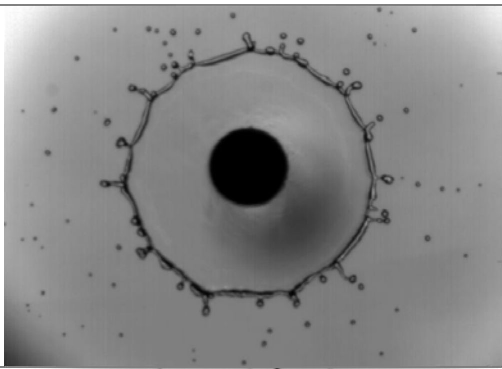
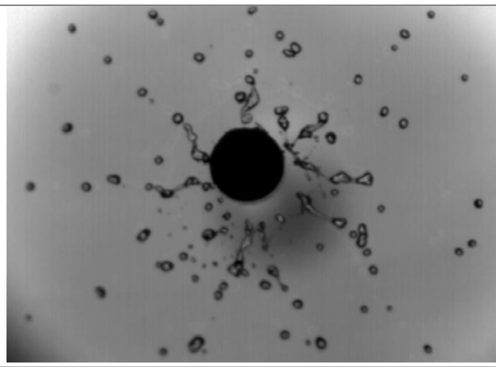
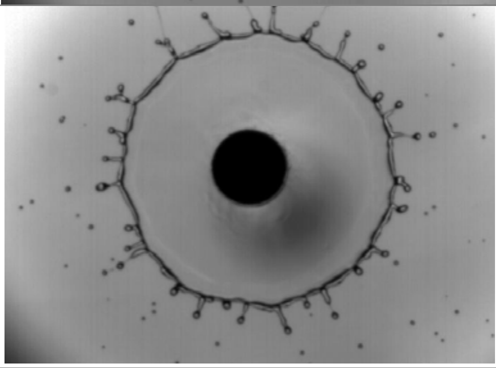
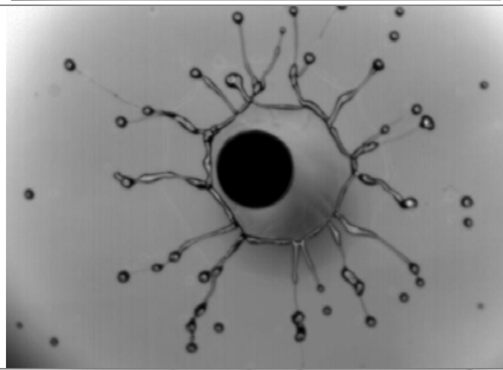
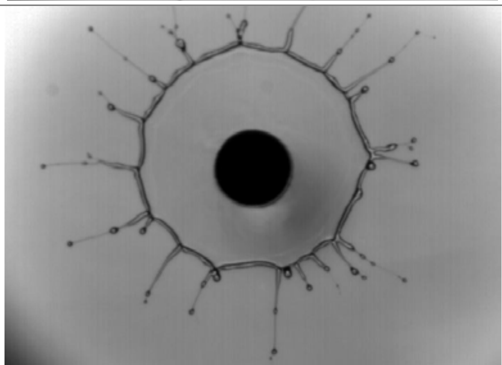
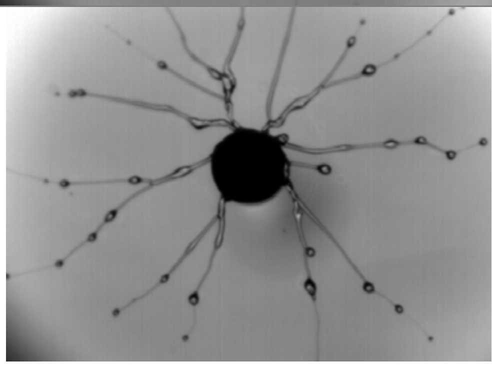
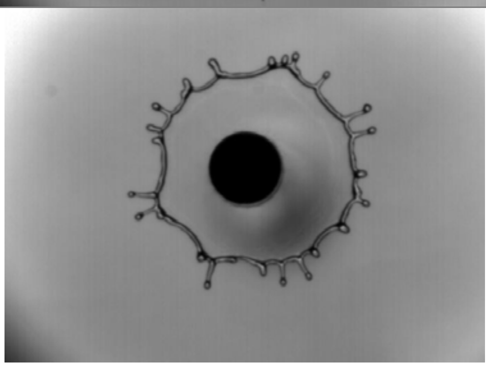
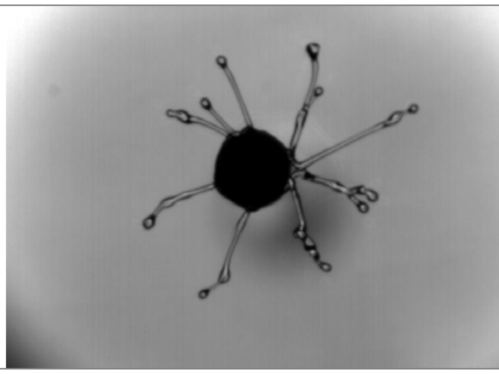
Liquid	*t*=3 ms	*t*=6 ms
Water		
PEO-1		
PEO-10		
PEO-100		

Figure 1. Top views of drops of various liquids impacting a disk-shaped target of diameter 4 mm (black circle in the centre of each frame). Drop diameter before impact is 2.7 mm; the impact velocity is 3.87 m/s. The motion of the drops before impact is directed from the reader to the figure plane. Time increases from left to right from 3 up to 6 ms.

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