An energy balance model for the maximum spread diameter upon droplet impact on surfaces of arbitrary wettability

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Abstract. Understanding the impact of liquid droplets on dry solid surfaces is relevant for many applications in natural, agricultural and industrial processes. In the absence of splashing, the droplet (initial diameter d_0) spreads on the surface until the wetting diameter reaches a maximum (d_m). Thereafter the droplet recoils and finally comes to rest. For technical applications, the maximum droplet spreading as characterized by the spreading factor $\beta_m = d_m/d_0$ is of special interest. Physically, β_m depends in a complex manner on Weber number (We), Reynolds number (Re) and surface wettability expressed by the contact angle θ. In literature, two approaches are common to derive relations of the form $\beta_m = \beta_m(We, Re, \theta)$. By rescaling of the cross-over between the capillary and the viscous regimes, several universal fitting models have been proposed depending on an impact parameter $P = P(We, Re)$ [1, 2]. For the second approach, which uses a mechanical energy balance, mechanistic models have been derived for certain regimes and conditions only while a universal mechanistic model for $\beta_m(We, Re, \theta)$ is still missing. The energy balance approach requires modeling of the gas-liquid interfacial area (S_m) and of the dissipation (W_m) at maximum spreading. In this contribution, significant progress on the development of a universal mechanistic energy balance model for the maximum spreading factor is reported. It is shown that the two commonly used models for S_m have significant shortcomings for hydrophobic surfaces. Therefore, an improved model for S_m is developed, which is derived from a spherical-cap approximation. As second novelty, a new concept for modeling dissipation at maximum spreading is proposed. In contrast to existing models, the new model does not relate dissipation at maximum spreading to polynomials in β_m. Instead, the new model uses $W_m = w_m W_{tot}$, where W_{tot} denotes the overall energy available for dissipation, while $w_m = w_m(P)$ with $P = We/Re^{0.4}$ is a function fulfilling $0 \leq w_m \leq 1$. Thereby, the proposed model respects for the first time the overall energy conservation principle of the entire spreading and recoil process. The new model yields an explicit relation $\beta_m = \beta_m(We, Re, \theta)$ that is developed and tested using experimental data [2, 3] covering wide ranges of We, Re and θ.

References

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