Assessment of heat transfer measurements at droplet/wall interactions: relation with the impact conditions

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Abstract

The study presented here addresses the heat transfer mechanisms occurring at droplet/wall interactions. The experiments encompass the measurement of the instantaneous surface temperatures and the evaluation of the heat flux between the liquid and the surface, within a wide range of impact conditions. The results stress a strong dependence of the cooling performance of the droplets with the liquid and solid thermal effusivities rather than with other parameters, such as droplet diameter and impact velocity. So, the cooling performance of the impinging droplets, determined from the experimental results can be well described in the dimensionless space Prandtl-Weber numbers.

Introduction

The study of the heat transfer mechanisms occurring at droplet/wall interactions is a hot topic in cooling systems based on droplet [1] or spray [2] impact. In these applications it is important to have a good indication of the surface temperatures at different working periods, to avoid system burnout. On the other hand, it is also essential to assess the heat transferred for different impact conditions to establish practical correlations, usually as a function of the Weber, the Reynolds, the Jakob and the Prandtl numbers, within the various heat transfer regimes, which often provide the foundation for more complex formulations concerning spray impact (*e.g.* [3]). This is the aim of the present paper, which addresses the analysis on the heat transfer mechanisms occurring between single droplets of several liquids and a variety of solid surfaces, made of diverse materials. The experiments focus on the assessment of the instantaneous surface temperature and heat fluxes for a variety of impact conditions. This procedure allowed concluding on the role of the various factors governing the heat transfer mechanisms and, consequently on the parameters which can be used to optimize the cooling performance of the impinging droplets.

Materials and Methods

The experimental work encompasses the measurement of the instantaneous surface temperatures, for a variety of liquid droplets (water, ethanol and methoxy-nonafluorobutane-HFE7100) impacting onto different surfaces, within a broad range of velocities ($1.3ms^{-1}<u_0<3.1ms^{-1}$). The surfaces are characterized by their *wettability*, quantified with the contact angle, θ and by the surface topography, as in [4]. Initial surface temperatures, T_{W0} are varied from room temperature up to 300ºC, although particular attention is put on the phenomena occurring up to the critical heat flux temperature, as this is the upper boundary for safe working conditions of cooling systems (*e.g.* in in electronic parts).

Sample Results and Discussion

The dynamic behaviour of a droplet impacting onto a solid and heated surface is well known to depend on the heat transfer regime. While T_{w0} remains below the saturation temperature of the liquid, the droplet spreads over the surface without phase change. The temperature at the interface (i.e. the contact temperature) determines the rate of heat exchange between the drop and the target. On the other hand, when phase change occurs, the theoretical analysis is rather more complex, but an increasing interest arises in the assessment of the temperature variation of the surface, as well as of the heat transferred at droplet contact, as the parcel of the latent heat increases the cooling potential of the system. However, care must be taken since, in this case, a thermal induced atomization will occur which can significantly reduce the contact area and residence period of the liquid over the surface. In line with this, the instantaneous temperature of the surfaces is measured for a variety of impact conditions as exemplified in Figure 1. The predominant role of the liquid properties when compared to that of the im-

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pact conditions is quite evident in the nucleate boiling regime. An associative effect of the liquid properties, particularly the liquid surface tension and the latent heat of evaporation will cause significant morphological differences in the lamellas of the various liquids, which contribute to the overall larger temperature decrease of the surface temperature when impacted by the water droplets.

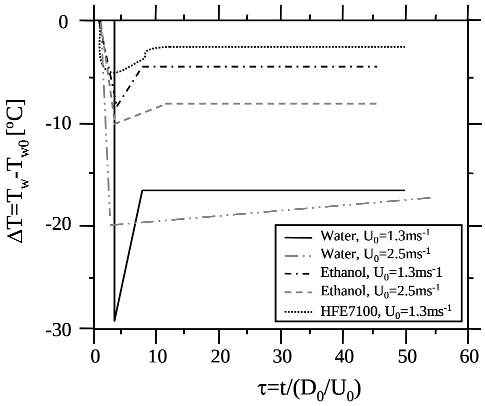

Figure 1. Instantaneous surface temperature, measured at the point impact of water (D_0=2.8mm), ethanol (D_0=2.4mm) and HFE7100 (D_0=2.0mm) droplets colliding on a stainless steel surface (R_a=0.31μm, R_z=2.32μm) at different velocities, within the nucleate boiling regime ($\Delta T=T_{w0}-T_{sat}$ =20ºC).

This trend is then relevant when analyzing the cooling effectiveness ξ of the impacting droplets, although in this case the impact conditions indirectly influence the results, as they will alter the wetted area and therefore the heat that is removed from the surface. So, following the definition of ξ in Pasandideh-Fard *et al.* [5] the cooling performance of the water droplets is always larger than that of the ethanol droplets, for various impact velocities (see Figure 2).

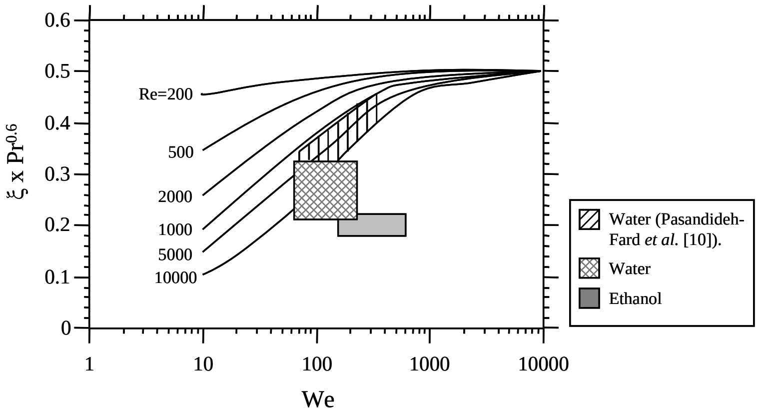

Figure 2. Cooling effectiveness ξ related with the Weber, the Reynolds and the Prandtl numbers, as in Pasandideh-Fard *et al.* [5].

The analysis performed here suggests that the cooling effectiveness of an impacting droplet can be well represented in the dimensionless space formed by the Prandtl-Weber numbers, as suggested by Pasandideh-Fard *et al.* [5], but not by the Reynolds number, particularly when other liquids besides water are considered. This may suggest an alternative scaling of the parameters, where more weight should be given to the surface tension forces in destabilizing the shape of the lamella and to the Prandtl number giving the relation between the thickness of the thermal and hydrodynamic boundary layers. However, a further investigation is still required until we can achieve a final form for such relation.

References

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