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Non-dimensionalisation parameters for predicting the cooling effectiveness of droplets impinging on moderate temperature solid surfaces

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The conjugate problem of fluid flow and heat transfer during the impact of water droplets onto a heated surface is studied numerically using the Volume of Fluid (VOF) methodology; adaptive grid refinement is used for increased resolution at the droplet moving interface. The phenomenon is assumed to be 2D-axisymmetric and the wall temperature is moderated to prevent the onset of nucleate boiling. Parametric studies examine the effect of Weber number, droplet size, wall initial temperature and liquid thermal properties on the cooling process of the heated plate during the impaction period. The main variables describing the evolution of the phenomenon are non-dimensionalised with expressions arising from the transient conduction theory. It is proved that for all cases examined, these non-dimensional expressions can be grouped together for describing the hydrodynamic and thermal behavior in a similar manner. Additionally, semi-analytic expressions are derived, which, for a given range of variation, describe the spatial distribution and the temporal evolution of the temperature of the wall as well also the heat flux absorbed from the droplet, cooling effectiveness and mean droplet temperature.

1. Introduction

The interaction of a droplet impinging on a solid wall is an interesting phenomenon which can be realized in many technological fields, such as internal combustion engines, cooling systems, fire suppression devices, printing and painting processes and metallurgical application amongst others. Previous studies suggest that the most influential parameters affecting the evolution of the phenomenon are the Weber (*We*) and the Reynolds (*Re*) numbers, the liquid–solid wetting contact angle and the surface roughness, the ambient gas pressure and properties, while the temperature of the wall relative to droplet's boiling point plays also a major role. The latter complicates even more the physical phenomenon since various hydrodynamic regimes may prevail at different wall temperatures. A combination of the aforementioned parameters can lead to various modes of impact such as spreading, rebounding or splashing followed by droplet disintegration into satellite droplets. On the other hand, the increase of the substrate's temperature can lead to four different regimes, namely film evaporation, nucleate boiling, transition boiling and film boiling. A detailed description of these phenomena can be found in [1] among others.

Due to its physical and industrial importance, a large number of experimental and numerical studies have been performed in order to shed light into the mechanisms governing this phenomenon. One of the earliest experimental studies was reported in [2], followed later by [3–17]. In these studies a wide range of *We* numbers, surface temperatures, liquid materials and surface qualities have been examined. Important information from these studies include the determination of the boundaries characterizing the outcome of the impinging regime, the estimation of the droplet lifetime impinging on a heated wall, the clarification of the parameters affecting droplet splashing and the estimation of maximum droplet spreading on the wall, as a function of the above mentioned parameters.

On the other hand, it is challenging to predict by numerical methodologies the various regimes identified during droplet collision on a heated surface. Over the past decades various methodologies have been proposed. The Marker and Cell (MAC) methodology was used by [18,19], the Lagrangian formulation has been adopted by [20–25], the Immersed Boundary Method (IBM) in [26,27] and the Level-Set (LS) methodology in [28]. One of the

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