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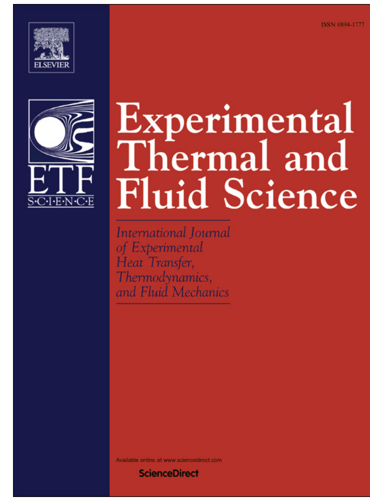

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Vortex-Induced Vapor Explosion during Drop Impact on a Superheated Pool

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Abstract

Ultra high-speed imaging is used to investigate the vapor explosion when a drop impacts onto a high-temperature pool. The two liquids are immiscible, a low boiling-temperature perfluorohexane drop, at room temperature, which impacts a high boiling-temperature soybean-oil pool, which is heated well above the boiling temperature of the drop. We observe different regimes: weak and strong nucleate boiling, film boiling or Leidenfrost regime and entrainment followed by vapor explosion. The vapor explosions were seen to depend on the formation of a rotational flow at the edge of the impact crater, near the pool surface, which resembles a vortex ring. This rotational motion entrains a thin sheet of the drop liquid, to become surrounded by the oil. In that region, the vapor explosion starts at a point after which it propagates azimuthally along the entire periphery at high speed.

Keywords: immiscible, vortex ring, vapor explosion, nucleate boiling, film boiling, Leidenfrost regime

1. Introduction

The impact of a drop onto a pool or solid surface is a very rapid process (Yarin (2006); Josserand and Thoroddsen (2016)). Despite a century-and-a-half of study following Worthington (1876), it is only in the last two decades, with the advent of high-speed video imaging, that significant progress has been made in understanding these phenomena (Thoroddsen et al. (2008)).

Such fundamental understanding of droplet-surface interaction is important for describing a number of industrial processes. The interaction between two liquids of different temperatures is quite common in applications like spray painting, cooling and cleaning, for example during chip manufacturing. Drop impacts on solids or liquid pools can result in splashing, droplet floating, bouncing, coalescing, or jet formation from the pool surface. Splashing is important for pesticide spraying on leaves, operating sprinkler systems, and even forensics, such as in blood splatter analyses. Which phenomenon occurs depends primarily on the non-dimensional parameters: Weber $We = \rho DV^2/\sigma$ and Reynolds numbers $Re = \rho DV/\mu$ where ρ is the fluid density, D is the droplet diameter, V is impact velocity, σ is the surface tension and μ is the dynamic viscosity.

Drop impact on hot or cold surfaces involves the additional complication of phase change of the droplet, but this case has been less studied to date. These are of interest in many areas: for solidification this includes icing on airplanes, inkjet droplet soldering and fabrication of displays and electronics (Rodriguez-Rivero et al. (2015)). Early studies were done by Aziz and Chandra (2000); Bhola and Chandra (1999). Boiling and evaporation on the other hand is important for safety and fire prevention, like the operation of sprinkler systems (Manzello and Yang (2004)); the spraying of molten materials into cold baths to produce powders and spray deposition (Yule and Dunkley (1994)), or drop encapsulation by immersion into reacting liquid baths (Lhuissier et al. (2013)). Droplets impacting solid surfaces heated well above their boiling point are subjected to violent nucleate boiling or Leidenfrost effect, also called film-boiling, where a stable layer of vapor insulates the drop from the solid surface. This layer reduces the friction between the two, thereby allowing the drop to skitter around, as oil drops on a pan (Quéré (2013)). High-speed imaging has recently revealed the details of the air-film dynamics in such impacts, Khavari et al. (2015); Tran et al. (2012, 2013b).

Herein we replace the hot solid surface with a very hot liquid, which has a much higher boiling temperature than the drop. In this configuration we can expect to find the so-called nucleate boiling, where bubbles form and collapse at the interface; as well as the formation of a stable vapor layer between the two liquids. The