Numerical and experimental investigations of crown propagation dynamics induced by droplet train impingement

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A B S T R A C T

In this study, hydrodynamics of HFE-7100 droplet train impinging on a pre-wetted solid surface was investigated experimentally and numerically. Experimentally, single stream of mono-dispersed droplets were produced using a piezoelectric droplet generator with the ability to adjust parameters such as droplet impingement frequency, droplet diameter and droplet velocity. Crown propagation events were imaged using a high-speed camera system given the high-frequency of droplet impingement. Relationships between droplet-induced crown propagation and crater formation were investigated experimentally. The high-frequency droplet impingement process was simulated numerically using CFD tool. Crown propagation dynamics were evaluated and analyzed experimentally and numerically, with reasonable agreement between the two methods. A revised theoretical crown propagation model based on numerical results is proposed in this paper, which takes into account the impinged liquid velocity distribution and film thickness at the moment of initial spot formation. The revised theoretical crown propagation model gives predictions with improved accuracy, which are in better agreement with the numerical results.

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1. Introduction

Droplet impingement is a common phenomenon encountered in nature and a number of technical applications. Examples include rain drop impact on solid surfaces (sandy surfaces, flat surfaces, porous surfaces) and liquid surfaces (deep liquid pool, thin liquid film), ink jet printing, surface coating, spray cooling of hot surfaces (semiconductor chips, turbine blades, machining work piece), and fuel injection in engines, to name a few. The associated phenomena of droplet impingement are diverse and strongly dependent on droplet impingement conditions. For instance, droplet may impact hot dry surfaces, thin liquid films or deep liquid pools, which exhibit different physical mechanisms.

The crown propagation dynamics induced by droplet impingement is a fascinating fluid dynamics behavior. Studies of droplet-induced crown propagation have been conducted by various researchers over the last two decades. Yarin and Weiss (1995) proposed a theoretical model to predict the radial extension of the droplet-induced crown. Rieber and Frohn (1999) revised the crown propagation model proposed by Yarin and Weiss (1995) by taking into account different assumptions. Shetabivash et al. (2014) also found that the model proposed by Yarin and Weiss (1995) greatly over-predicts time-dependent crown propagation diameter.

Even though the studies of droplet impingement have received considerable attention in the last two decades, very few studies have considered a theoretical crown propagation formulation for droplet train impingement. The crown propagation model proposed by Yarin and Weiss (1995) should be revised so that accurate time-dependent crown propagation diameter predictions can be obtained. Furthermore, recent studies about droplet train impingement (Zhang et al. 2014; Soriano et al. 2014; Soriano, 2011; Alvarado and Lin, 2011; Trujillo et al., 2011; Trujillo and Lewis, 2012) have provided different definitions for droplet-induced crater and crown. Therefore, there is a need to differentiate between droplet-induced crater and crown, and to investigate the physical relationship between them. With the goal of gaining a better understanding of the hydrodynamics of droplet train impingement, well-controlled experiments, and numerical simulations have been performed with the following specific objectives:

• To clarify and simplify the definitions of droplet-induced crater and crown.
• To investigate the physical relationships between droplet-induced crater and crown.
• To revise the Yarin and Weiss (1995) Model for the purpose of obtaining accurate crown propagation predictions.

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