International Communications in Heat and Mass Transfer 93 (2018) 93–99

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Evaporation dynamics of different sizes sessile droplets on hydrophilic and hydrophobic heating surface under constant wall heat fluxes conditions

Ming Gao*, Peng Kong, Li-xin Zhang

Shanghai Key Laboratory of Multiphase Flow and Heat Transfer in Power Engineering, School of Energy and Power Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China

ARTICLE INFO

Keywords:
Droplet evaporation
Contact angle
Wettability
Constant heat flux
Drop size

ABSTRACT

In this study, an experimental investigation has been carried out to study evaporation of sessile droplets with different volumes on a heating surface under constant heat flux conditions. In this experiment, two sessile droplets were placed on a hydrophilic and a hydrophobic heating surface side by side. The droplets size ranged from 2 μl to 5 μl, and heat flux ranged from 1272 W/m^2 to 7810 W/m^2. A high-speed camera was used to record the changing shapes of two sessile droplets. Effects of droplet size on dimensionless contact angle, dimensionless contact diameter, dimensionless droplet height and dimensionless evaporation rate, are presented.

1. Introduction

Droplet evaporation widely exists in daily life and industrial applications, such as in spray cooling [1,2], condensate droplets removal from rear-view mirror or observation window [3], inkjet printing [4,5], spraying of pesticides [6], combustion engineering [7], spray painting and coating [8], etc. In 1977, Picknett and Bexon [9] investigated the evaporation of methyl droplet and described two distinct evaporation modes: CCR mode (constant contact radius mode, the contact angle reduces while the contact radius is pinned) and CCA mode (constant contact angle mode, the contact radius shrinks while the contact angle is kept constant).

In some cases, the droplet evaporation followed mixed mode (the contact angle and radius change at the same time) or stick-slip modes [10]. On evaporation modes, different researchers gave different conclusions. Yu et al. [11] as well as Fang et al. [12] found that when droplets evaporation on a hydrophobic surface, the droplets followed the CCR mode at the initial stage, and then the CCA mode was dominated. Subsequently, Yu et al. [13] studied sessile water droplets evaporating on both PDMS and Teflon surfaces, and found that all experiments on the hydrophobic surface began with the CCR mode, switched to the CCA mode after a short transition and ended with the mixed mode. Birdi and Vu [14] as well as Uno et al. [15] found that the droplet evaporation followed CCR mode on a hydrophilic surface, while the droplet dominated by the CCA mode on a hydrophobic surface. Furthermore, Shin et al. [16] investigated water evaporation on different wettability surfaces, and they found that both the contact angle and contact area changed with evaporation time at the end of droplet evaporation. The water droplet on a super-hydrophobic surface did not have pinning section during the evaporation.

In addition to the above mentioned droplet evaporation modes, many researchers had studied droplet evaporation rates. Most of previous experimental studies [17–19] were carried out under constant wall temperature conditions. Misyura [17] kept the heating surface temperature at steady temperatures of 25 °C, 75 °C and 95 °C. In experiments of Crafton and Black [18], two heaters made of aluminum and copper, were maintained at 60 °C, 80 °C, and 95 °C for water droplets while wall temperatures at 60 °C and 75 °C were maintained for n-heptane experiments. Kim et al. [20] and Putnam et al. [19] studied droplet evaporation in an extreme condition. In their experiments droplet evaporated on superheated surfaces. For example, in experiment by Kim et al. [20], a liquid droplet was placed on a heating block whose temperature was significantly higher (over 250 °C) than the boiling point of the liquid. They found that the droplet could hover over the heated surface without contact due to the Leidenfrost effect. In the experiment by Putnam et al. [19], the microdroplet evaporated on Al thin-films with surface temperatures up to 250 °C, and found that the evaporation time is less than 1 s. Other investigators conducted their experiments under normal atmospheric condition [9,11,12,15,16,21–24]. For example, Yu et al. [11] kept the substrate temperature at 23 °C in the ambient conditions, Fang et al. [12] kept at 25 °C, Picknett and Bexon [9] kept at 22–23 °C, Shin et al. [16] kept at 20 °C, Lee et al. [23] kept at 25 °C and 40 °C, and Furuta et al. [24] kept at 22 °C. In fact, these conditions are equivalent to the constant wall temperature conditions. This is because the substrate temperature in experiment was equal to the ambient temperature, and the volume of

---

* Corresponding author.
E-mail address: gaoming@usst.edu.cn (M. Gao).

https://doi.org/10.1016/j.icheatmasstransfer.2018.03.007

Nomenclature

D	Contact diameter, mm
H	Droplet height, mm
t	Evaporation time, s
t_a	Total evaporation time, s
q	Heat flux, W/m^2
V_0	Initial droplet volume, m^3
θ	contact angle, °
V	volume of droplet, m^3

Greek symbols

β	power exponent

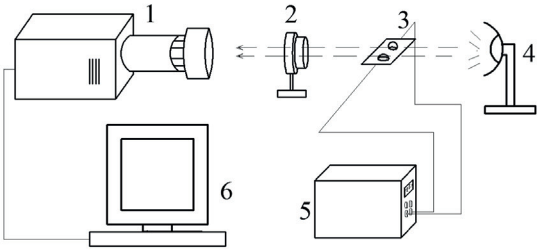
Subscripts

0	initial parameter
a	Total parameter

droplets was usually only a few microliter. Therefore, its evaporation would not affect wall temperature.

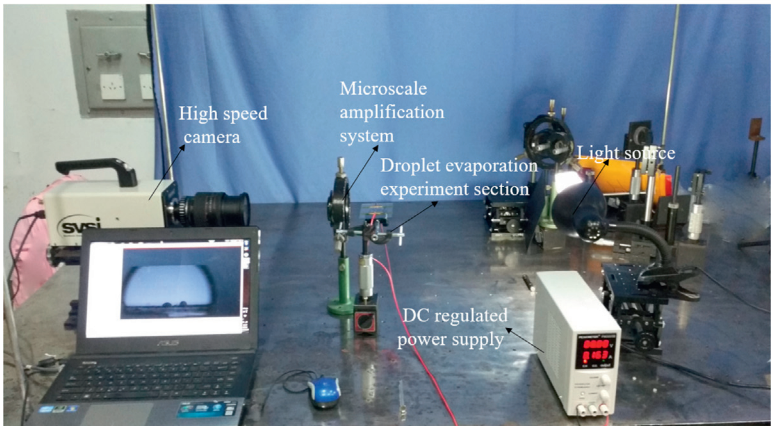
Some researchers had studied the effect of droplets size on evaporation. Nguyen et al. [21] studied the evaporation of sessile water drops on hydrophobic silicon wafers and Teflon surface under constant wall temperature conditions. The droplet sizes were 2.0, 2.5, 3.0 and 4.0 μl, and they found that the evaporation process firstly followed the CCR model and then followed the CCA model. The evolution of the droplet volume in time had a linear trend initially, whereas towards the end of the droplet life time, the behavior tended to deviate from the linear trend, and the trend was similar with those of Mollaret. et al. [25]. Furuta et al. [24] studied the behavior of ultra-small water droplets (80-100 nL) on a superhydrophobic surface with nanoscale and micrometer-scale random roughness, and kept at a constant temperature 22 °C. They found that the square of contact radius and the square of droplet height decreased linearly with evaporation time. Yu et al. [13] studied the evaporation of sessile water droplets (2 μl and 4.0 μl) on both Polydimethylsiloxane (PDMS) and Teflon surfaces at 23.6 °C, and found that all experiments began with CCR mode, switched to CCA mode after a short transition and end with mixed mode. Lopes et al. [26] conducted their experiments with pure water drops of different sizes on hydrophilic surfaces, and found that thermal properties of the substrate had a strong influence on evaporation time.

As seen from the above literature review, previous researchers' experiments were conducted on surfaces at constant wall temperature. As far as the authors are aware, only a few previous experiments were carried out on droplet evaporation with constant wall heat flux heating surface. Gao et al. [3] investigated evaporation of a sessile 3 μl DI water droplets on hydrophilic and hydrophobic heating surfaces under constant heat flux conditions with a heat flux ranging from 1153 W/m^2 to 6919 W/m^2, they found that for both hydrophilic and hydrophobic surface, the droplet evaporation proceeded in CCR mode at most of droplet evaporation time, and at the end of droplet evaporation time, droplet evaporation proceeded in a mix mode, but no CCA mode was found. In this paper, we carried out further experimental investigations on effects of sessile droplets sizes (2 μl, 3 μl and 5 μl) on their



1 high speed camera, 2 microscale amplification system, 3 droplet evaporation experiment section, 4 light source, 5 DC regulated power supply

(a) Schematic of experimental system



(b) Photo of experimental setup

Fig. 1. Experimental system.