International Journal of Heat and Mass Transfer 71 (2014) 691–705

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Effect of static contact angle on the droplet dynamics during the evaporation of a water droplet on the hot walls

Deendarlianto [a,b,*], Yasuyuki Takata [c], Sumitomo Hidaka [c], Indarto [a,b], Adhika Widyaparaga [a,b], Samsul Kamal [a,b], Purnomo [a,b], Masamichi Kohno [c]

[a] Department of Mechanical & Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Jalan Grafika No. 2, Yogyakarta 55281, Indonesia
[b] Centre for Energy Studies, Gadjah Mada University, Sekip K-1A Kampus UGM, Yogyakarta 55281, Indonesia
[c] International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

ARTICLE INFO

Article history:
Received 27 September 2013
Received in revised form 7 December 2013
Accepted 26 December 2013
Available online 25 January 2014

Keywords:
Wettability
Spray cooling
Wetting limit temperature
Ultraviolet irradiation
Droplet

ABSTRACT

The effect of surface wettability on the collision dynamics and heat transfer phenomena of a single water droplet impacting upon a heated solid surface has been studied experimentally. To modify the surface wettability, two modules of stainless steel coated by TiO_2 were employed. The first module was induced by ultraviolet irradiation to produce the hydrophilic surface, while the second one was not. The diameter and the depth of coating surface were 30 mm and 200 nm, respectively. The droplet size was varied from 1.90 to 2.90 mm and substrate temperature raised up to 340 °C. The interaction of an impact water droplet with a heated solid surface was investigated using a high-speed video camera.

As a result, it was found that; (1) in the lower surface temperature region the evaporation time decreases as the static contact angle decreases, (2) the wetting limit temperature decreases with the increase of static contact angle, (3) the ultraviolet irradiation on the TiO_2 surface does not change the qualitative behavior of the evolution of wetting diameters, and (4) the maximum wetting diameter increases with the decrease of static contact angle below the wetting limit temperatures.

1. Introduction

Spray cooling is the most popular technique of water-cooling in the iron and steel making industries. It is commonly applied in the manufacture of steel, internal combustion engines, and turbine blades, in order to cool down the hot surfaces, in both very high and medium temperature regions. Spraying a hot surface with liquid droplets yields much higher heat fluxes than can be obtained by forced convective cooling. The high heat transfer rate is beneficial because they allow the size, cost, and complexity of heat exchanger equipment to be reduced. Application of spray cooling thus promotes the ability to greatly reduce production cost and develop accurate and efficient heat transfer process for the making of high quality metal product which will ultimately determine the profitability of the final product.

Understanding the physics of the phenomena is essential in order to build a model capable of predicting the heat transfer with a high accuracy. However, under practical conditions, the dispersion of the liquid results in the generation of numerous droplets which collectively can be difficult to study systematically. To investigate the underlying phenomena of spray cooling transient heat transfer characteristics in a more manageable fashion, droplet studies can be applied. The physics of a single droplet impact on heated walls can be used to predict the global heat, transfer characteristics of an entire spray [1].

Laboratory studies of spray cooling have typically measured the temperature variation and the effect of liquid properties on the evaporation [2–6]. They observed that the droplet impact dynamics depend on both substrate temperature and impact velocity. If the surface temperature is above the boiling point of the liquid, nucleate boiling will commence with vapor bubbles forming in surface crevices, detaching and rising into the liquid. Once the surface temperature rises above the "Leidenfrost point" droplets go into a state of film boiling and are seen to levitate above the solid surface, supported on a film of their own vapor. Furthermore, Moita and Moreira [7] noted also that those experiments intend to identify the fluid-dynamic regimes of the droplet interaction and to quantify the outcome of droplet impact (size, velocity and angle of ejection of secondary droplets, as well as mass deposited onto the surface).

Despite many such investigations in the past, many fundamental questions remain to be answered. One issue which has received

* Corresponding author at: Department of Mechanical & Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Jalan Grafika No. 2, Yogyakarta 55281, Indonesia. Tel.: +62 274 521673.
E-mail address: deendarlianto@ugm.ac.id (Deendarliant).

0017-9310/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.12.066

Nomenclature

d_o	initial droplet diameter (mm)
D	wetting diameter (mm)
D_{max}	maximum wetting diameter (mm)
Re	Reynolds number (–)
R_o	initial wetting radius (mm)
R_{max}	maximum wetting radius (mm)
T_s	surface temperature (°C)
We	Weber number (–)
Greek symbols	
β	spreading ratio, (D/d_o), (–)
σ	surface tension (N/m)
θ	contact angle (°)
μ	Viscosity (Pa s)

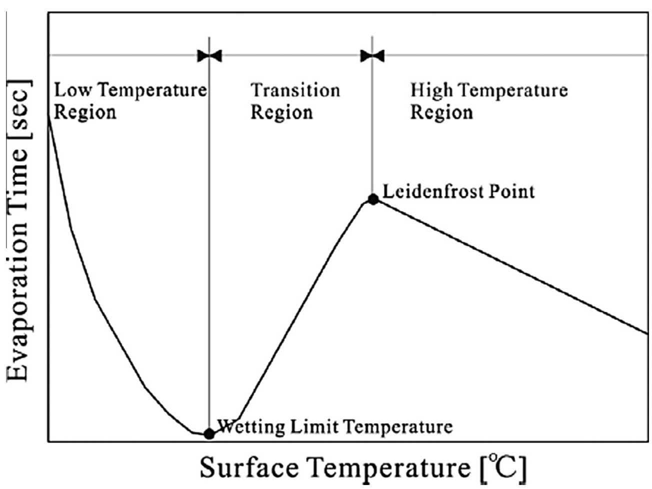

Fig. 1. Evaporation curve [13].

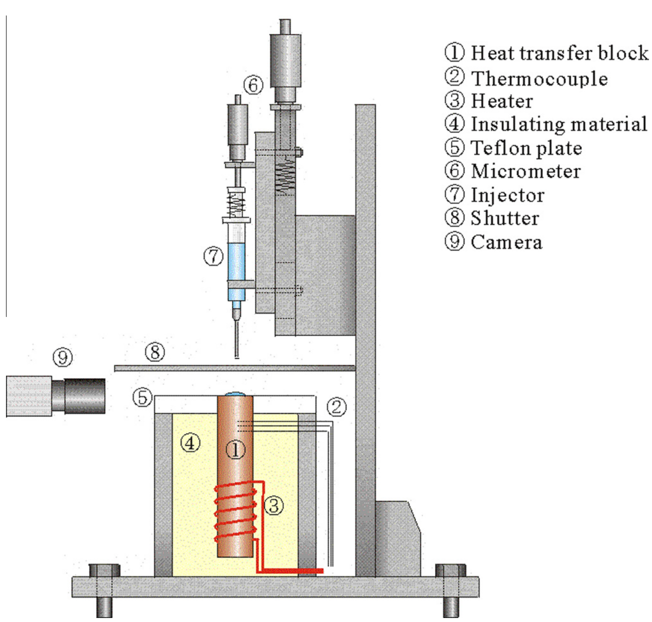

Fig. 2. Schematic diagram of the experimental apparatus.

inadequate attention is the effect of wetting angle on the evaporation of water droplet on a heated solid surface. This may be due to the difficulties of altering the static contact angle as the only exclusive parameter with all the other parameters being unchanged. The introduction of ultraviolet irradiation (UV) on the TiO_2 coating of a solid surface to alter static contact angle can be one of the solutions for this problem as reported by [8]. From this fact, we expect that heat transfer characteristics of liquid–vapor phase change phenomena like boiling and condensation can be controlled and/or enhanced by UV irradiation making use of TiO_2-coated surface. In addition, it is also important to investigate the different characteristics between TiO_2-coated surfaces and normal uncoated surfaces.

The objective of this study was to experimentally investigate the isolated effect of the static contact angle on the collision dynamics and heat transfer phenomena of a water droplet impacting upon a heated solid surface. To realize this aim, we made coated stainless steel surfaces with TiO_2. By irradiating the TiO_2 surface using UV light, the static contact angle of a droplet on

Table 1
Specification of the heat transfer surfaces.

No.	Surface treatment	Static contact angle (θ)
1	TiO_2 coating with ultraviolet irradiation (**UVW**)	0°
2	TiO_2 coating without ultraviolet irradiation (**UVN**)	(22–23)°
3	Normal stainless steel (**NS**)	88°

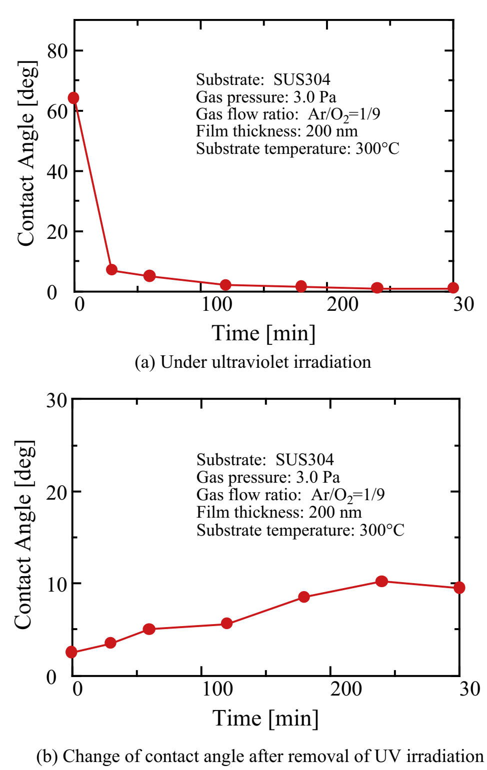

Fig. 3. Time variation of contact angle.