

CHARACTERISTIC OF MICRO EMISSION BUBBLES IN A DROPLET IMPINGING ON A HEATING SAPPHIRE SURFACE

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ABSTRACT

A technique for cooling that has been found to have a higher heat transfer coefficient than one that involves circulating cooling water over a heated surface is the spraying of fine water droplets onto a surface. This study aims to examine and elucidate the mechanism behind the behaviors that resulted in the formation of bubbles in a droplet's core when a water droplet collided with a heated surface. To clearly see the bubble that forms at the solid-liquid contact interface, a transparent sapphire was utilized as the heating surface. A high-speed video camera captured the boiling behavior from the horizontal view. The fluctuation of the bubbles was examined to ascertain their behavior during the boiling process. To ascertain the impact of surface wettability, two distinct heating surfaces were also employed. Compared to the original sapphire surface, the heated sapphire surface with hydrogen peroxide plasma layer had improved wettability thus higher bubble point density. At 320°C, the lifetime of bubbles was the longest, and the vertical fluctuation of the fluid that could be perceived as the bubbles moved was also intense. Moreover, the maximum instantaneous velocity of the fluid determined from the bubble movement at this time exceeded 2 m/s.

Keywords: Droplet, Bubble Generation, Impingement, Heat Transfer, Fluctuation

1.0 INTRODUCTION

Researchers have devoted many years to studying the droplet impingement phenomena in order to obtain a thorough understanding of the relationships among mass, momentum, and heat transmission [1]. For commercial and industrial applications such nozzle spraying and material quenching, research on droplet cooling of any surface, including metal surfaces, is essential [2]. Spray cooling is one of the key cooling methods used to remove heat and change the mechanical properties of materials during heat treatment operations such as quenching. Combining a liquid drop with the phase change and convection modes of heat transmission results in high heat flux [3]. Boiling is one of the greatest ways to enhance heat transfer. During spray cooling, early bubbles enlarge and congregate inside a thin liquid layer before collapsing onto a heated surface [4]. Most experimental phenomenological studies focused on the fundamental behaviors and characteristics of nucleation, transition, and film boiling for single droplets and droplet-droplet combinations. Important differences between each of the numerous boiling processes were identified and described.

When the temperature of the heating surface reaches a certain range, a black area that is believed to be caused by the coalescence and disappearance of these bubbles appears on the hot surface. This is known as the boiling phenomenon in solid-liquid contact between a droplet and heated sapphire. Photographs of the formation behavior of the tiny vapor bubble that formed in the liquid-solid contact surface (wetting surface) at the start of the collision were taken in a number of research experiments that observed droplet behavior from the backside of the heating surface, such as quartz and sapphire. In the temperature range of 180°C to 520°C, the impact of the heating surface temperature and the duration of time after the collision on the quantity of bubble generation was examined [5-8]. This study focuses on the behavior of the bubbles that are created in the droplet's center when the heating surface's temperature is changed. A high-speed camera is used to capture the boiling phenomenon from the heating surface's back while also examining the behavior and process of the black part. Observing and clarifying the liquid supply process to the hot surface is the aim.

By irradiating plasma onto the sapphire surface, creating boiling on that surface, and comparing it with the phenomenon that takes place on normal sapphire surfaces, it also clarified the characteristic of modifying the wettability of the surface.

2.0 METHODOLOGY

A high-speed camera set up to capture images of the boiling event during droplet contact from the back is depicted in Figure 1. The camera is set to record at 50,000 fps, and a shutter speed of 1/270,000 sec. The experiment was conducted at Department of Mechanical Science and Technology, Gunma University, Japan. A sapphire glass measuring 30 mm in diameter and 8 mm in thickness is used as the heating surface. The two end surfaces are polished to resemble lenses. The sapphire was placed horizontally inside a copper block that has a heater implanted in it. The transformer's voltage was changed to alter the heating surface temperature. K-type thermocouples were affixed with ceramic adhesive to two different spots on the heating surface in order to measure the temperature of the surface. The initial heating surface temperature (T_w) for the experiment was set between 180°C and 320°C. The droplets are made from sufficiently degassed distilled water, which is continuously dripped from a nozzle and captured by a shutter.

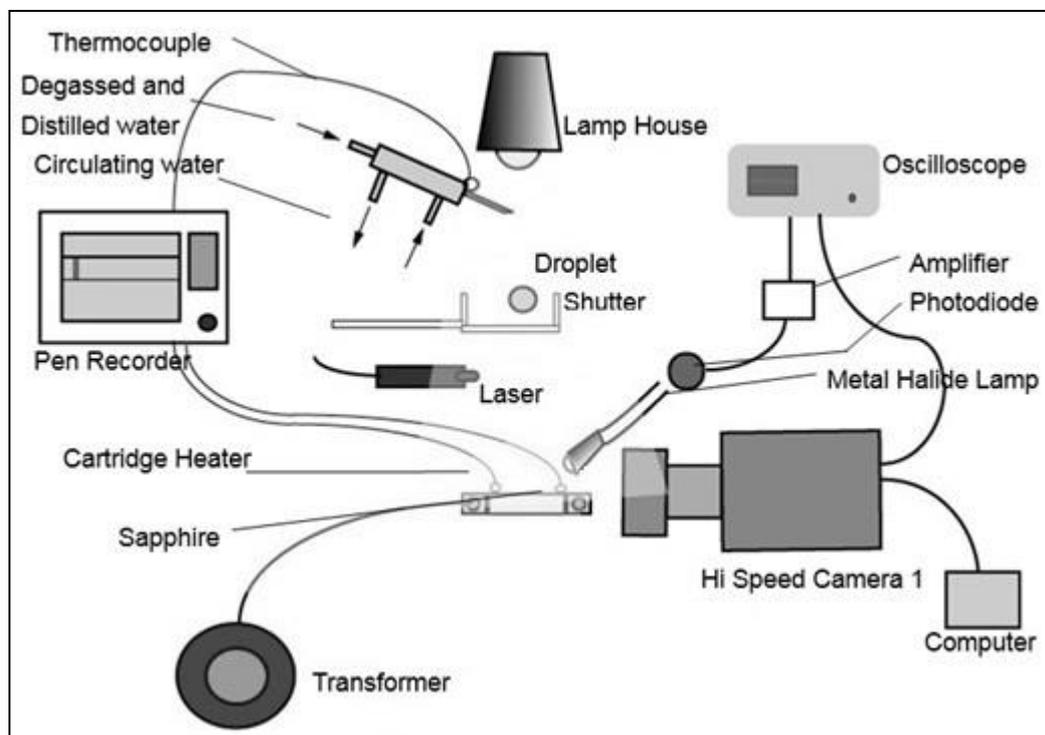


Figure 1: Experimental apparatus

The shutter is only shifted during experiments so that one droplet can make contact with the heated surface's center. To keep the droplet temperature T_1 at 18°C, cold tap water was constantly circulating around the nozzle. Droplet falling height was set to 65 mm, and droplet diameter was set to 3.8 mm. The collision Weber number needs to be taken into account while thinking about a droplet collision system. This value determines how the droplet behaves when it falls; if the value is high, the droplet hitting the wall will fragment. The following equation (1) yields the collision Weber number:

$$We = \frac{\rho v^2 L}{\sigma} \quad (1)$$

where density, $\rho \left[\frac{kg}{m^3} \right]$, velocity, $v \left[\frac{m}{s} \right]$, representative length, $L[m]$, surface tension coefficient, $\sigma \left[\frac{N}{m} \right]$, Collision Weber number, $We = 70$.

A passing sensor was positioned to record the falling drops. The camera received the data and processed it using a pulse generator to modify the photo shoot's start time. Moreover, sapphire was exposed to hydrogen peroxide plasma (static contact angle: 45° for original sapphire, 30° for plasma-treated sapphire) in order to alter its wettability. A manual counter was used to count bubbles.

3.0 RESULTS AND DISCUSSION

The static contact angles of water droplets captured on each surface utilized in this experiment are displayed in Figures 2 and 3. Here is a list of the reference static contact angles for the sapphire that was originally utilized in this experiment and the sapphire that was exposed to hydrogen peroxide plasma. Utilizing distilled water as the droplet material, room temperature water was discharged via the identical nozzle. The contact angle of normal sapphire is greater than that of sapphire exposed to hydrogen peroxide plasma when comparing each heated surface. This demonstrates that the easiest sapphire to wet is that which has been exposed to hydrogen peroxide plasma radiation on each heated surface. The material with the highest wettability and the largest surface area exposed to heat should have the best evaporation properties if the evaporation properties are dependent on the contact angle.

In Figure 4, the behavior of the droplet after it collided with the heated wall was captured at a heated surface temperature of 260°C , a frame rate of 50,000 fps, and a shutter speed of $1/270,000$ sec. Air bubbles floating and staying in the center of the droplet moved up and down over time.

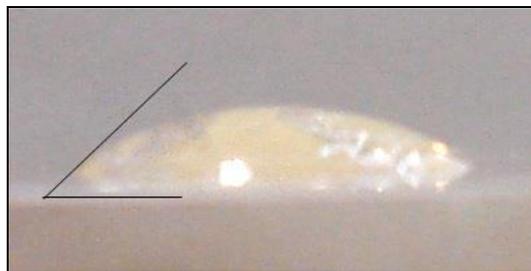


Figure 2: Static contact angles of droplet at 45° on original sapphire

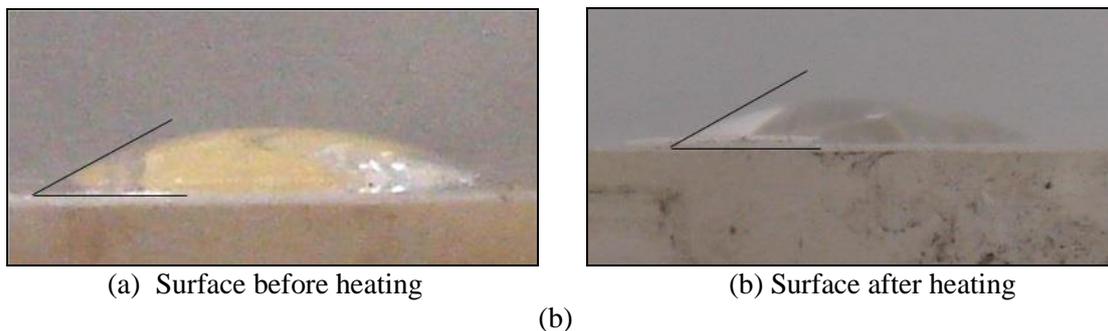


Figure 3: Static contact angles of droplet at 30° on sapphire irradiated with hydrogen peroxide plasma

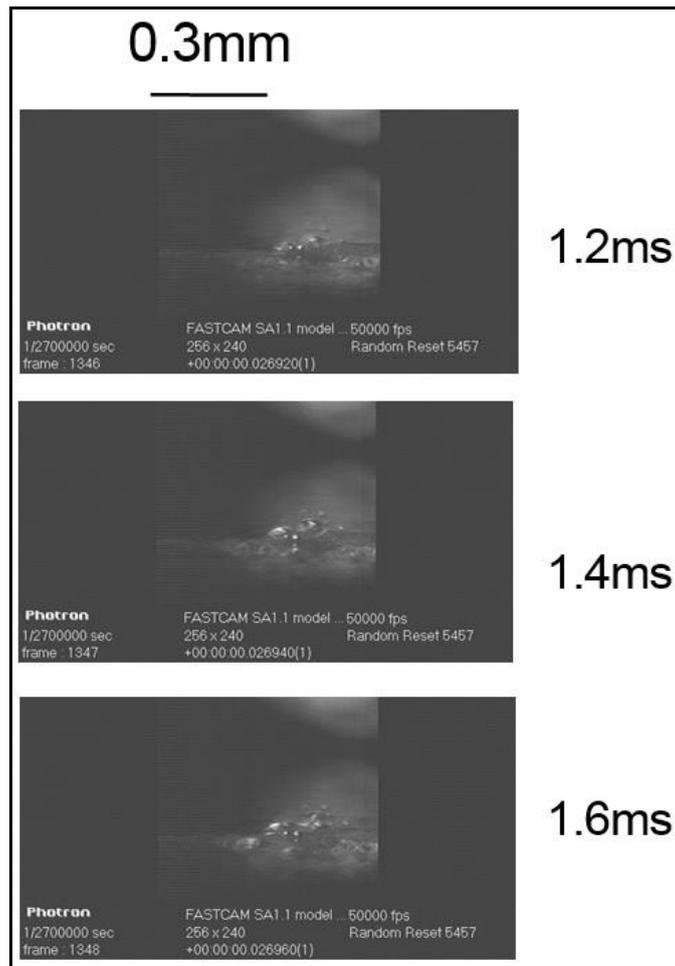


Figure 4: Bubbles behavior on sapphire surface from horizontal direction at 260°C

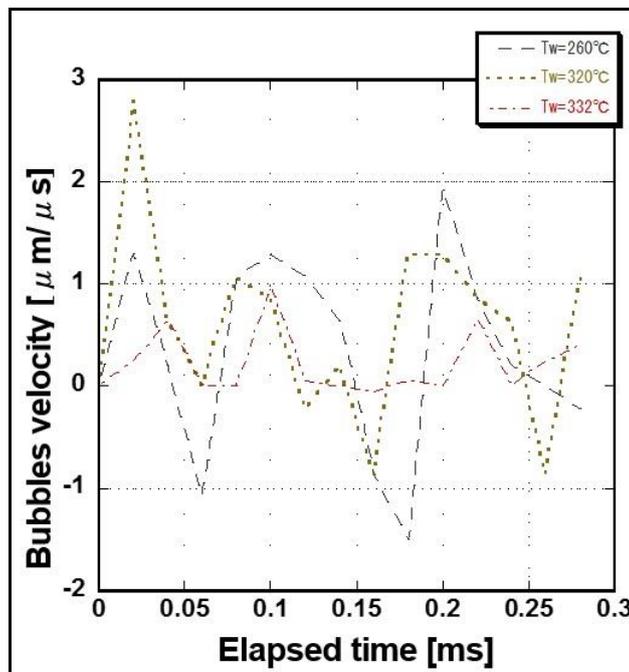


Figure 5: Velocity of rising bubbles in the droplet central part at 260°C, 320°C and 332°C

Figure 5 shows the vertical movement speed fluctuations in the liquid when the upward velocity of the bubbles floating and staying inside the droplet is taken as positive at heating surface temperatures of 260°C, 320°C, and 332°C. That is, these bubbles act as tracers for visualization, and the flow pattern within the droplet can be understood from their movement.

From Figure 5, the accumulated bubbles at 260°C moved about the same distance both upward and downward. Also, at this temperature, compared to 320°C and 332°C, bubbles were generated, and the time when they rose to the surface and stayed there was the fastest after the collision. When the heating surface temperature was 320°C, the life of these floating and staying bubbles was the longest, and the vertical vibration of the fluid that could be perceived as the bubbles moved was also intense.

The maximum instantaneous velocity of the fluid determined from the bubble movement at this time exceeded 2 m/s.

4.0 CONCLUSION

The sapphire heated surface pretreated with hydrogen peroxide plasma had better wettability and increased bubble point density than the original sapphire surface. At 320°C, the life of these floating and staying bubbles was the longest, and the vertical vibration of the fluid that could be perceived as the bubbles moved was also intense. The maximum instantaneous velocity of the fluid determined from the bubble movement at this time exceeded 2 m/s.

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