

An experimental method to simultaneously examine hydrodynamic and thermal interactions during droplet collision

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1. Introduction

During the reflood phase following loss of coolant accident (LOCA) in PWR, dispersed flow film boiling plays an important role in preventing the fuel cladding overheated before it is fully rewetted. According to Chatzikyriakou et al. [1], the droplet-wall collision heat transfer in film boiling contributes to about 10% of the overall cooling rate. Therefore, this subject has been continuously studied in the field of nuclear engineering.

Droplet collision dynamics and heat transfer behaviors have been investigated using various visualization methods. Shirota et al. [2] visualized the bottom side during a droplet collision using total internal reflection (TIR), observed different dynamics of droplet collision such as the transition boiling regime, Leidenfrost boiling regime, and contact/non-contact regimes. Lee et al. [3] visualized the bottom side and collision dynamics using X-ray high-speed videos. Zhang et al. [4] and Jung et al. [5] performed side-view visualization using high-speed video and simultaneously measured the heat flux distribution. For heat flux analysis, Zhang et al. [4] used a differential thermocouple and Jung et al. [5] used IR thermometry. However, there was no study that simultaneously performed the bottom side, side-view visualization, and heat flux measurement.

The behaviors of droplets that can be observed through lateral visualization include rebound, breakup, spreading diameter, and residence time. Contact/non-contact, transition boiling, Leidenfrost boiling temperature, vapor fraction, and boiling point can be confirmed when observing the bottom side. Using a high-speed IR camera, it can see how much the hot substrate is cooled by the droplet collision. In this study, direct visualization of the bottom side and side shadowgraph and temperature measurement using an IR camera is performed simultaneously during droplet collision.

2. Experiment

2.1 Sample for simultaneous imaging

A hybrid sample was fabricated for simultaneous imaging of bottom side hydrodynamics and thermal interaction. A semicircular of Pt thin film was deposited on a sapphire substrate. This hybrid sample was named the half & half sample. When measuring

the temperature using an IR camera, the sapphire is transparent to the infrared ray, so the temperature of the Pt deposition surface can be measured. The dynamics of the droplet collision can be observed through the transparent sapphire part during direct visualization at the bottom side as shown in Fig. 1. When the droplet and the sample was non-contact, the visible light was reflected from the sapphire and looks white, and when the droplet was contacted with the sample, the visible light was transmitted and appears black. Therefore, the bottom side of the droplet collision could be observed.

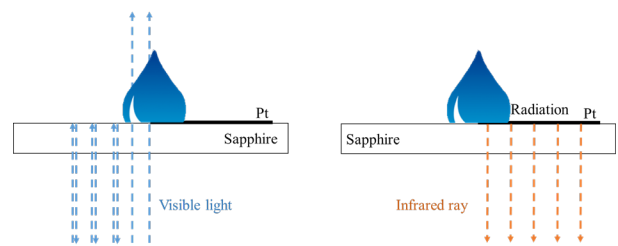


Figure 1. Half & half sample

2.2 Experimental method

Fig. 2 shows the schematic diagram of the experimental setup. Droplets were loaded using the 31-gauge needle ($D_0 = 260 \mu\text{m}$, $D_i = 130 \mu\text{m}$). Double layer water tank system is selected to maintain the working fluid constant and saturated. The temperature of the droplets is heated by the water in the outer tank through the band heater. The single droplet was loaded using the syringe pump and dropped by gravity. The speed of the droplet was determined by adjusting the height of the needle.

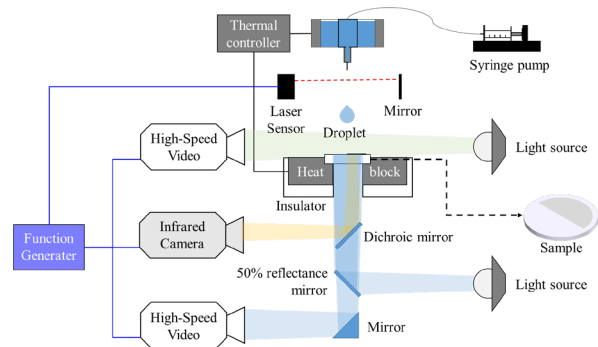


Figure 2. Schematic of the experimental setup

The half & half sample was used, with a diameter of 50mm and a thickness of 5mm. The temperature of the sample was controlled through the SS304 heating block and four cartridge heaters. There was the hole in the center of the heating block, so it was possible to visualize the bottom using the high-speed camera and measure the temperature using the IR camera. The frame rate of IR camera was 1,500Hz and the frame rate of high-speed video was 100,000Hz. During the droplet collision, two high-speed video and IR cameras were synchronized through the function generator. When the laser sensor detects that the droplet falls, a signal is sent to the function generator to be photographed. Two light sources were installed to take high-speed video, and the light source illuminated the lower part of the sample through the 50% reflective mirror when visualizing the bottom side.

The temperature of the sample was measured through an IR camera by reflecting infrared light through a dichroic mirror. Infrared rays emitted from the sample and reflected by the dichroic mirror are counted with the IR camera. The counted value is converted into temperature data using the previously calibrated value.

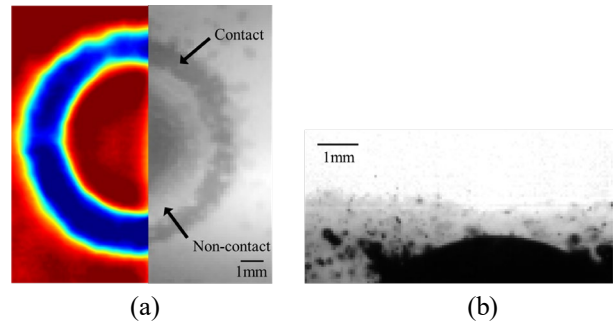


Figure 3. (a) bottom side direct observation and IR thermometry, (b) Side visualization at 210°C and after 4.8ms at the droplet collision point

3. Preliminary test result

Fig. 3 (a) shows the temperature data and direct visualization of the droplet obtained simultaneously through the half & half sample at weber number 48. The left side was obtained through the Pt-deposited semicircle as temperature data, and the right side was obtained through the transparent sapphire semicircle as the lower direct visualization image. In addition, it is possible to compare the side-view image of the droplet collision at the same time in Fig. 3 (b). Pixel resolution

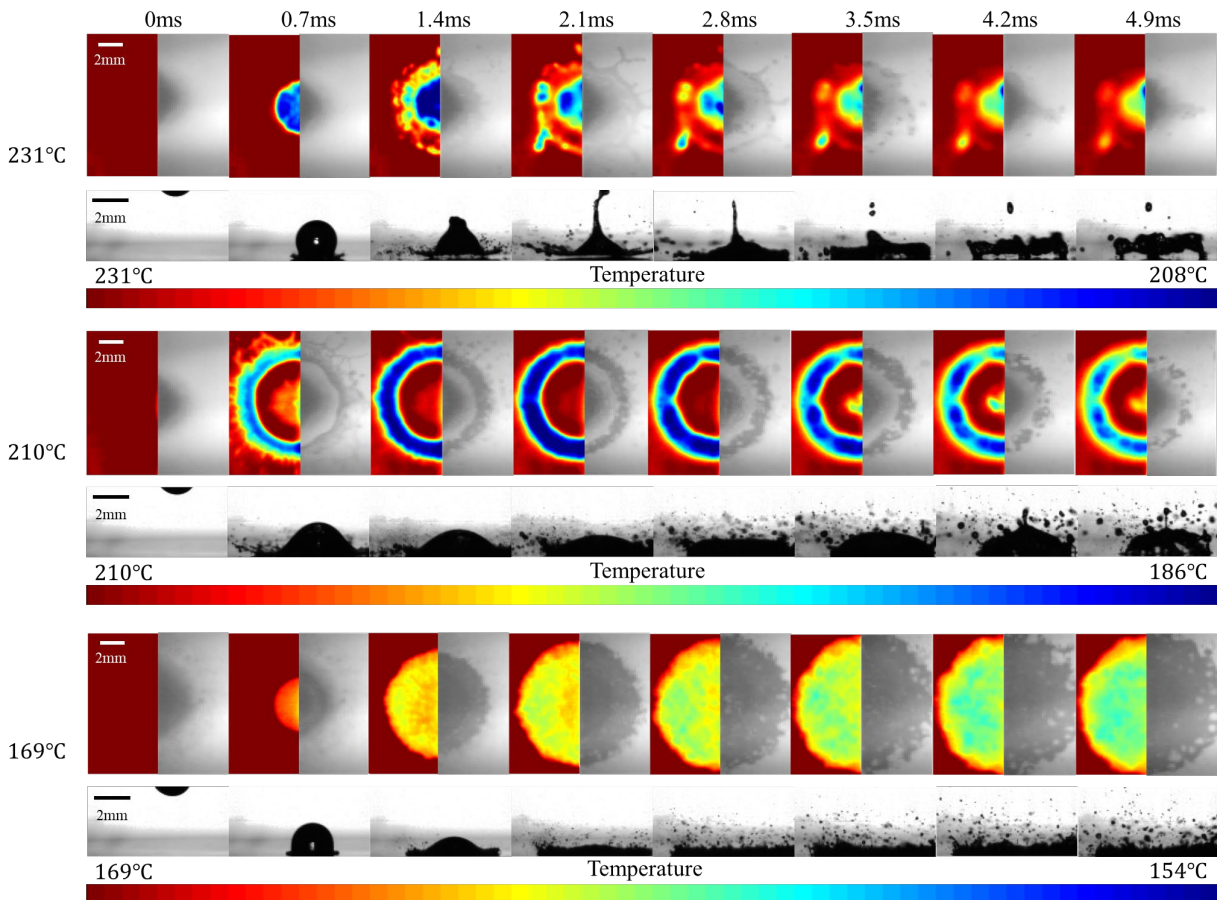


Figure 4. Simultaneous visualization image by temperature over time

was 142 μ m for IR camera, 148 μ m for bottom side high-speed camera, and 58 μ m for side high-speed camera. In this way, whether the droplet has contacted the sample, rebounds, or breaks up, and the temperature and heat flow rate can be determined in the situation.

Fig. 4 shows the synchronized visualization images according to the temperature (at 231 $^{\circ}$ C, 210 $^{\circ}$ C, 169 $^{\circ}$ C) of the sample at weber number 48. Looking at the temperature data, it can be seen that when the temperature of the sample was high (at 231 $^{\circ}$ C, 210 $^{\circ}$ C), a relatively large temperature drop occurs at the beginning of the droplet collision. And when the temperature of the sample is low (at 169 $^{\circ}$ C), cooling occurs a lot over time. The reason for such a temperature distribution can be analyzed through side and bottom side visualization images. From the side visualization image, it can be confirmed that the droplet rebounded when the temperature was high (at 231 $^{\circ}$ C). As the temperature decreased, it is confirmed that the spreading diameter increased. Through the bottom side visualization image, it is confirmed that the contact area decreased over time for the high temperature sample (at 231 $^{\circ}$ C, 210 $^{\circ}$ C). And in the case of a low temperature sample (at 169 $^{\circ}$ C), the contact area does not decrease over time and sticks to the sample and boils. In addition, it is confirmed that the contact area increased significantly as the temperature decreased. As described above, the behavior of the droplets confirmed through the side and bottom side visualization data can be analyzed for the temperature of the sample, enabling various interpretations.

4. Conclusion

In this study, an experimental setup to simultaneously examine hydrodynamic and thermal interactions during droplet collision in film boiling was developed and a preliminary test was demonstrated. Using the developed setup, comprehensive experimental studies of droplet-wall collision phenomena in film boiling can be performed in various conditions relevant to dispersed flow film boiling which appears in water-cooled nuclear reactors.

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