The effects of wall temperature on single saturated droplet-wall collision heat transfer

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1. Introduction

When a large break loss of coolant accident (LOCA) occurs in a pressurized water reactor (PWR), the coolant is supplied by the emergency core cooling system for preventing melting of the heated fuels [1]. During reflooding phases, the droplet-wall collision heat transfer is one of the important phenomena for cooling the overheated fuel cladding and determining maximum peak cladding temperature.

Under reflooding conditions, the temperature of droplet is considered as saturation condition. The droplet impinging on heated fuels above 350 ºC has the various diameters ranged of 0.2 – 2 mm. The collision velocity of the droplets ranged from 1 to 10 m/s under very low collision angle (< 10º) which results in Weber number lower than 30 [2-3].

Many studies in droplet/wall interactions [4-5] have reported that the initial wall temperature is one of important parameters, includes impact velocity, collision angle, droplet temperature and diameter, on the changes of droplet dynamic behaviors and heat transfer characteristics. Very recently, a few studies such as Lelong et al. [6] and Dunand et al. [3] investigated the effects of wall temperature on heat transfer characteristics of a subcooled droplet impinging on heated surface using infrared camera. However, previous results provide some errors in quantitative results for developing and evaluating the heat transfer models due to the inherent effects of droplet subcooling which is reported by Shi et al. [7].

Therefore, the main purpose of this study is to gain an understanding of the effects of wall temperature on a saturated droplet-wall collision heat transfer. The heat transfer characteristics is experimentally investigated on the basis of quantitative heat transfer amount by using the infrared thermometry technique.

2. Experiments

2.1 Experimental setup

Fig.1 shows a schematic diagram of the experimental setup for the droplet wall collision test, that consisted of visualization equipment, a single droplet generation system and test plate. The infrared camera (FLIR SC6000) synchronized with a high-speed video (Phantom v7.3) with a frame rate of 1.5kHz.

A droplet is generated by using a syringe with 31-gauge needle. The velocity of droplet falling down by gravity is determined height between test plate and droplet generation system. The temperature of droplet is maintained in a saturation condition using the heater mounted to the syringe.

Fig. 2 shows the geometric conditions of sample for measuring surface temperature and controlling the initial wall temperature. A specimen is made of sapphire which has highly transparent in infrared light. The upper side of sapphire sample was deposited with 100 nm thickness of platinum film which is opaque with infrared light. The Pt film allows to measure the surface temperature which changes while the droplet impacts the heated sample. Initial wall temperature of the sample is controlled by direct joule heating through an electrode connected to DC power supply

Table 1 summarizes the experimental conditions based on typical conditions of reflooding phase. In this study, deionized water was used as the working fluid in experiments.

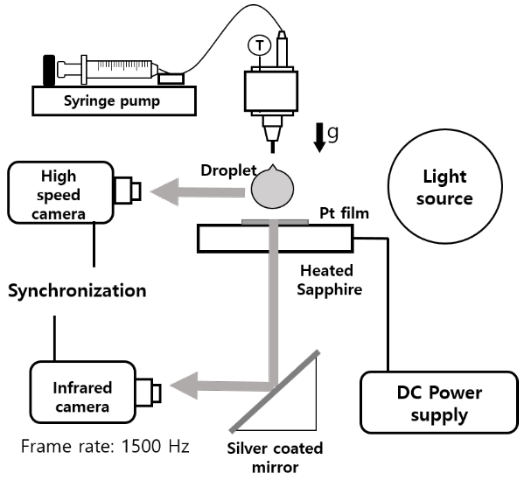


Fig1. Schematic of the experimental apparatus [8]

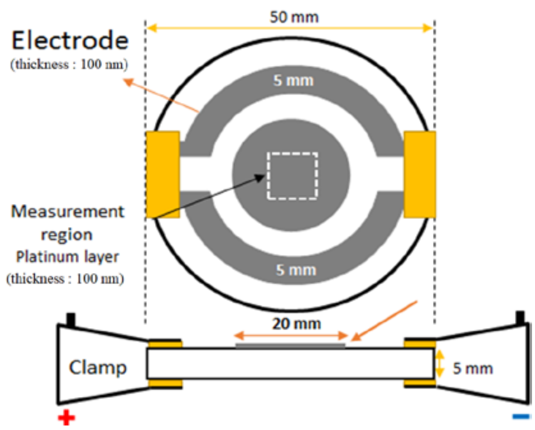


Fig. 2. Geometric conditions of sample for measuring surface transient temperature [8]

Table. I Experimental condition

Parameters	Experiments
Wall temperature (℃)	200 ~ 580
Pressure (MPa)	0.1
Droplet temperature (℃)	100
Normal velocity (m/s)	0.2, 0.74
Weber number	5, 20
Droplet diameter (mm)	2

2.2 Data reductions

Heat flux distribution and effectiveness are important parameters as quantitative data representing heat transfer characteristics of droplet impinging on heated surface. The wall heat flux was obtained by solving the transient heat conduction equation [7]. The heat transfer amount per collision (E_d) was calculated by taking the integral of the heat flux during collision time (T_R) and heat transfer area. The effectiveness of heat transfer during collision was defined as the ratio of the heat transfer amount (E_d) to the energy to evaporate the single droplet.

$$E_d = \int_0^{T_R} \int_A q''_w(x,y,t) dAdt \quad (1)$$

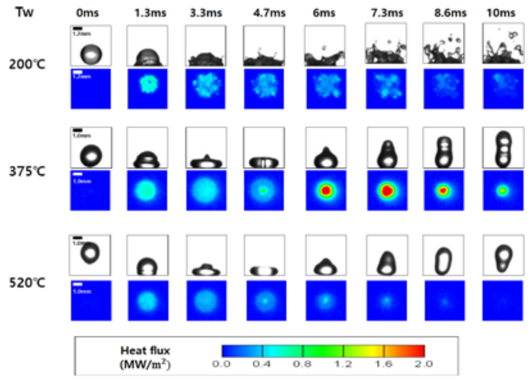
$$\varepsilon = \frac{E_d}{m_D h_{fg}} \quad (2)$$

3. Result and Discussion

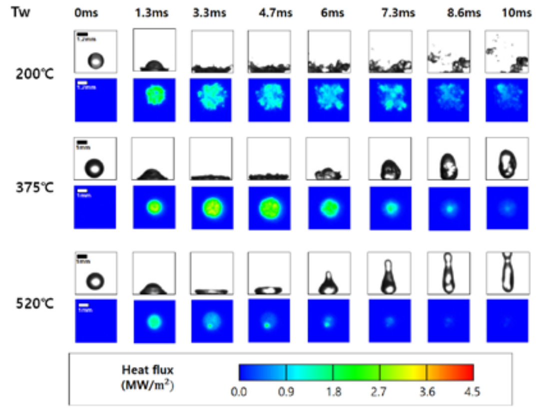
3.1 Visualization of droplet dynamics and heat flux

Fig. 3 (a) shows the visualization results of a saturated droplet impinging onto a wall heated to the temperature ranged from 200 to 520 °C at We_n=5. At 200 °C, which was the lowest surface temperature tested in this study, the droplet wet the surface and break down small droplets. The heat transfer of droplet continuously occurs while droplet stick to surface. At 375 °C and 520 °C, two dynamic results have same trend which droplet deformed and rebound after collision. At 520 °C, however, the mild heat flux was detected compared to results of 375 °C, which indicates insulating vapor film is more formed underneath the impacting droplet.

Fig.3 (b) shows that dynamic behaviors and heat flux distributions of saturated droplet at We_n=20. Comparing the results shown in Fig. 3(a), the tendency of dynamics behaviors at the same wall temperature was similar with that of We_n=5, but the magnitude of heat flux was significantly increased because of droplet velocity. The effect of collision velocity makes easily to contact with surface.



(a) Normal Weber number 5

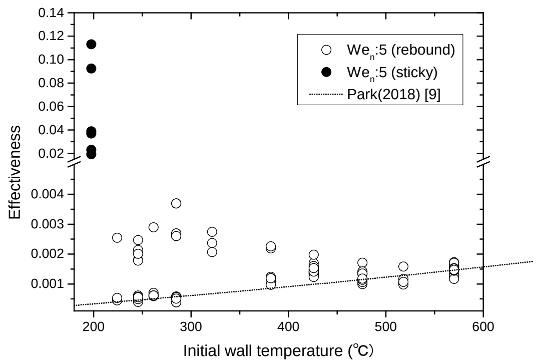


(b) Normal Weber number 20

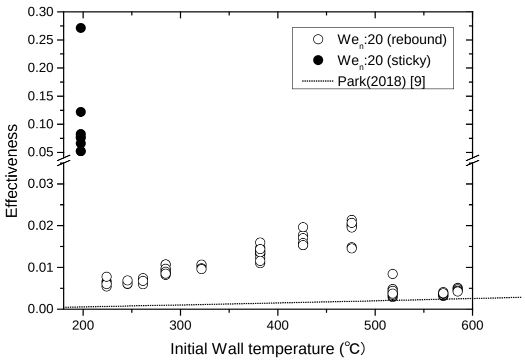
Fig. 3. Visualization of droplet dynamics and thermal characteristics

3.2 Effectiveness

Fig.4 (a) show that calculated effectiveness of droplet-wall collision heat transfer by integrating local surface heat flux. When normal weber number is 5 and wall temperature is above 500 °C, experimental results are in agreement with magnitude of results during film boiling by Park [9]. Experimental results consider as the film boiling because of good agreement with the prediction results.



(a) Normal Weber number 5



(b) Normal Weber number 20

Fig. 4. Effectiveness in accordance with wall temperature

However, there are some differences between experiment results and prediction model below 500 ºC. The results have higher value of effectiveness of prediction model. Calculated effectiveness are increased due to local contact despite the vapor film to rebound droplet. Tendency of results is gradually consistent with prediction model as wall temperature increase. It means that the rate which local contact occur has reduced.

Fig.4 (b) shows results effectiveness of Weber number 20. The overall trend of effectiveness as a function of the wall temperature is quite different to that at We number 5. Because the velocity of droplet ignores the thickness of the vapor film and cause to contact between droplet and the wall. The results of effectiveness have high value because of local contact between droplet and wall.

4. Conclusions

In this paper, effect of wall temperature of saturated droplet impinging on heated surface were experimentally studied using the synchronized high-speed visualization and infrared thermometry.

The heat transfer amount and effectiveness in a single droplet/wall collision can be used to determine dynamic behavior and heat transfer characteristics of saturated droplet.

It is found that effects of wall temperature vary to produce the amount of the vapor film beneath the impacting droplet.

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