Volume 6 Issue 1 (2018) 25-27 ISSN 2347 - 3258
International Journal of Advance Research and Innovation

Experimental study of droplet impact on a cold surface

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Article Info
Article history:
Received 02 January 2018
Received in revised form
20February 2018
Accepted 28 February 2018
Available online 15 March 2018

Keywords:
Droplet, electrostatic force, droplet impact, weber number, hydrophobic, hydrophilic, cold surface.

Abstract
Experimental study of a droplet impingement on a cold surface has been performed with the aim of visualizing the temporal variation of droplet impact and of observing frost formation and ice adhesion on the surface. The NaCl solution was mainly used and, droplets were formed at a tip of sharp needle by using electrostatic potential. The free falling droplet was impinged on a cold flat surface and visualized using a high-speed camera and LED light. Captured images were used to measure and calculate the falling speed before the impingement on the surface. After having impingement on the surface, the droplet has a frost formation and ice adhesion, whereas the droplet in room temperature has a process of rebound, recoil and splash. Depending on the size of the droplet, we observed that the frost formation and ice adhesion was highly dependent upon the critical size of droplet yielding different Weber numbers.

1. Introduction

Frozen formation and ice adhesion cause various problems in bio-devices, aircrafts, power lines, roads ships, wind turbines, oil platforms, and network systems. To resolve these issues, different anti-icing/ice-phobic techniques such as electric heating, hot air, and anti-icing liquid have been suggested over the last several decades[1–6].

Among them, passive de-icing systems that prevents ice formation or reduces ice adhesion and accumulation without additional power input or active controls have been of particular interest. Some of these studies indicate that ice adhesion reduces with the increasing hydrophobicity of the surface. More recently, the use of hydrophobic surface treatments for reducing ice accretion has been extended to super-hydrophobic surfaces [7–8].

Some of these studies show reduced accretion of ice formed from super-cooled water that was either sprayed or simply poured onto the test super-hydrophobic surfaces [9–10]. Although ice formation from super-cooled droplets is important in various practical applications, frost formation is another common mechanism for ice accretion on surfaces.

The objective of this study is mainly to understand the impact of a droplet on a plane and cold surface with the changing droplet size and observe how the droplet does rebound, recoil and splash, and if there is a frozen formation, then the critical size of the droplet can be determined in terms of temperature. In this approach, we are also focusing on making the droplet size depending on the strength of electrostatic force surrounding the droplet. The dynamic behavior of droplet impact was not only observed, but we also observed the frost formation of droplet and ice adhesion properties on cold surface.

2. Experimental methods

In this study, in order to detach the droplet from the needle tip under electrostatic forces, the applied voltage was set to be less than 2kV, which controls even a small-sized droplet properly. For the proper application, the droplet was earlier mixed with NaCl powders 1mol%. These small droplets (under around 6ul) also have a condition of free fall through the air toward the ground.

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Figure 1 shows the experimental setup to generate a cold surface on the chamber by using Peltier thermoelectric element inside the constant temperature chamber. In addition, the droplet of NaCl solution falls freely on the cold cupper plate. In order to measure the temperature on the cupper plate affected by the impingement of droplet, the thermo-couple wires (k-type) connected to the PXI system (National Instrument) were used.

3. Results and discussions

Snapshot images of the droplet shape are shown in Fig. 2. These images visibly decrease the diameter of droplet with the increasing voltage. In addition, Tables 1 and 2 show the droplet speed just before the impact of the droplet. As shown in the Tables, the impact speed remains almost constant before the impact. This result shows that it had no variation in voltage, but as the height of the free falling increases the impact speed increases.

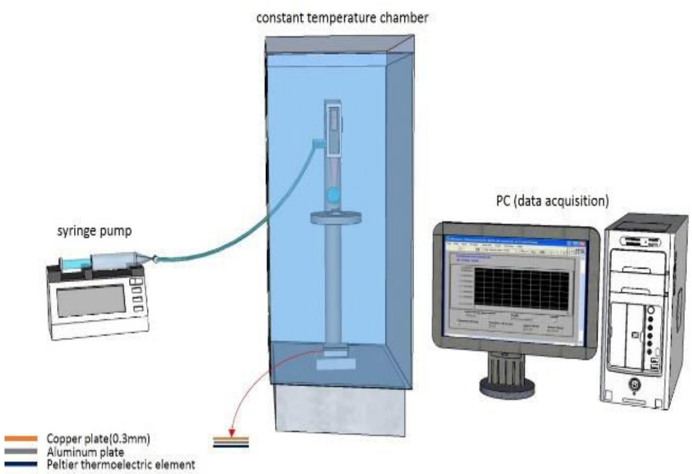

Fig. 1 Experimental setup

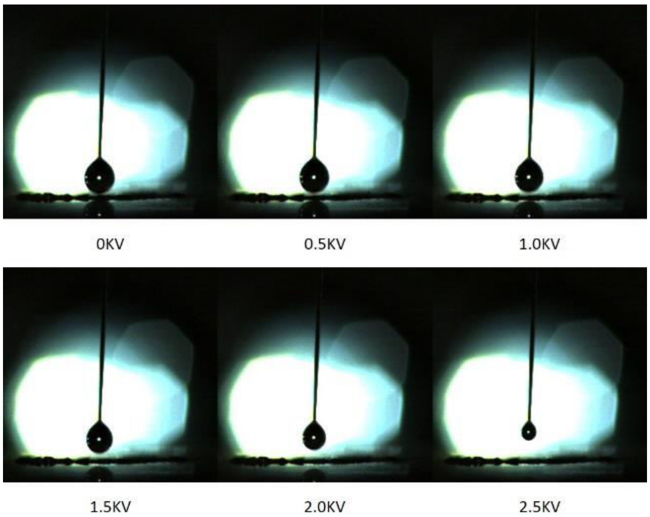

Fig. 2 Snapshot images of droplet size

Figure 3 shows the measurement points of temperature on the cupper plate. Ch3 is the right central point on the cupper plate, and Ch4 and Ch5 are located in 5mm away vertically and horizontally from Ch3. Figure 4 shows that droplet impact on hydrophobic surface, As soon as the droplet impacts on the cold plate, the central temperature (Ch3) of plate suddenly rises up and takes time to be steady state. Due to the hydrophobic surface, the central temperature (Ch3) increases around a factor of two higher than outer temperature (Ch4). And Fig.5 shows that droplet impact on the hydrophilic surface, Since the hydrophilic surface spreads the droplet to radial direction, both temperature distributions seem similar. The outer temperature (Ch4) seems to have slightly faster increase than the center temperature (Ch3).

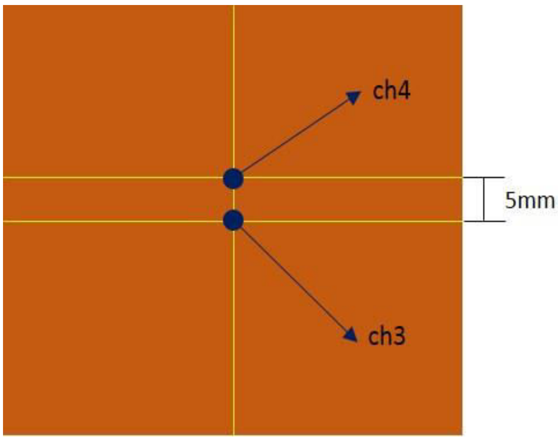

Fig. 3 Temperature measurement point

Table 1. Droplet speed just before the impact (10cm)

Voltage(kV)	Speed(m/s)	Voltage(kV)
0	1.111	0
2.0	1.092	2.0

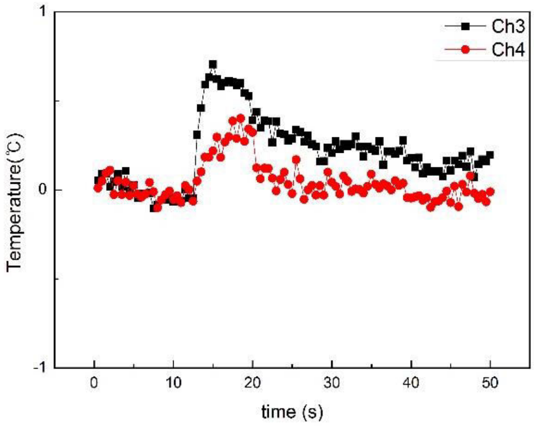

Fig. 4 Temperature measurment of hydrophobic surface

Table 2. Droplet speed just before the impact (35cm)

Voltage(kV)	Speed(m/s)	Voltage(kV)
0	1.111	0
2.0	1.092	2.0

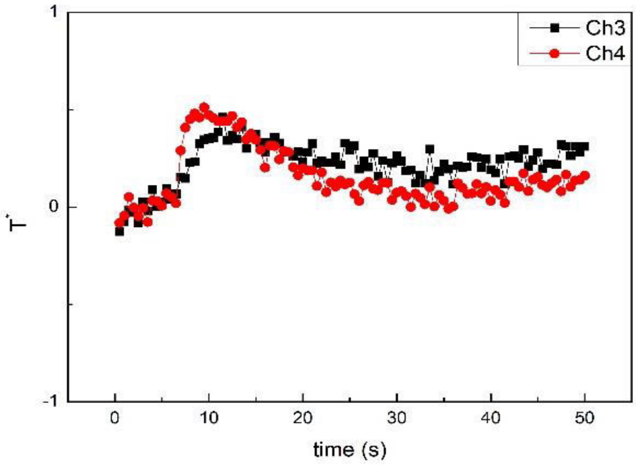

Fig. 5 Temperature measurment of hydrophilic surface

4. Conclusions

This preliminary study aims to generate a possible environment of the frozen formation and ice adhesion on cold surface after an impact of a free fall droplet having various diameter. As soon as the droplet impacts on the cold surface, it starts forming a frozen and ice on the surface, whereas the droplets on plane surface form a variety of droplet dynamics. This preliminary works have not completed yet, and then we will have a further work on the impact of the droplet on the cold surface.

Acknowledgment

This work was supported by 'Human Resources Program in Energy Technology' of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (no. 20164030201230). In addition, this work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (no. 2016R1A2B1013820). This research was also supported by the Fire Fighting Safety & 119 Rescue Technology Research and Development Program funded by the Ministry of Public Safety and Security (MPSS-2015-79)

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