VISUALIZATION STUDY ON THE IMPINGEMENT OF LIQUID DROPLETS ON A HOT SURFACE

Dongyeon Kim*, Seung Jae Yi*, Hyun Dong Kim*, Kyung Chun Kim *
*School of Mechanical Engineering, Pusan National University, Busan, Korea

Summary Hydrophobic characteristics of high temperature metal surface were investigated by the high speed visualization technique. An aluminum plate was used as the sample plate and the initial diameter of water droplet was 2 mm. Transient behaviours of the single droplet impinging on the surface with and without heating were captured by using a high speed camera with 4,000 frames per second. The Leidenfrost phenomenon was demonstrated for the case of 300ºC surface temperature, however there were no rebounding of droplet on the cold plate due to hydrophilic nature. Experimental results show that the shape of droplet, which is impinging to the surface, is different according to the Weber number. The overall surface characteristics of the heated surface were very similar with those of super hydrophobic surface.

INTRODUCTION

The impingement of droplets on a hot surface is generally used for various industry applications, such as spray cooling, spray coating and rewetting of nuclear reactor. Recently, studies on micro jets are progressing from the nozzle to impingement of oil droplets. The behaviour of droplets are related to surface temperature, dropping velocity and surface tension at impingement. When droplets impinging onto a high temperature plate, it may spread out, splash and rebound on the surface. Then it boils and vanishes quickly. However, if the temperature of the solid surface is high enough, the drop is not any more in contact with the surface, but levitates above its own vapor [1]. This nature is called Leidenfrost phenomenon. One of the main factors that affect the Leidenfrost temperature is Weber number. The effect of initial Weber number, initial droplet diameter, solid surface superheat and wettability has been studied by Xie and Zhou [1]. Recently, measurement and analysis of heat transfer from hot surfaces to non-wetting droplets were carried out by means of high resolution infrared microscopy [2]. The effect of Weber number and spread factor of a droplet impinging on different characteristic of surface has also been studied [3]. The used super hydrophobic surfaces had 150º of the contact angle. The hysteresis behaviour of the contact angle of super hydrophobic surface has been investigated [4]. In the present study, hydrophobic characteristics of high temperature surface at over Leidenfrost point is investigated by high speed visualization technique using an ultra high speed camera.

EXPERIMENTAL APPARATUS AND PROCEDURE

Fig.1 shows the schematic of the experimental apparatus. The droplet is made through a 31G injection needle. The injection needle is placed onto the aluminium plate. The injection flow rate is 50 μℓ/min and droplet siz e is 2 mm. An aluminium plate is heated up to 300 ºC by a hotplate. A high speed camera (Photron Fastca m SA1.1) was used for visualization, and the frame rate was set to be 4000 fps. A 250W halogen lamp was used for illumination. Droplet was made by deionized water. The main factor of this experiment is Weber number. Weber number is related to density, velocity, diameter and surface tension. In this experiment, dropping height was changed from 10 mm to 210 mm for changing drop velocity. Initial height from the plate was from 10 mm to 210 mm, so that Weber number was changed from 0.91 to 117.54, respectively.

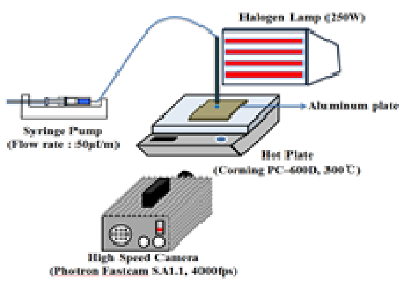
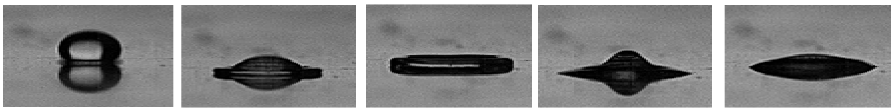


Figure 1 Experimental apparatus schematic

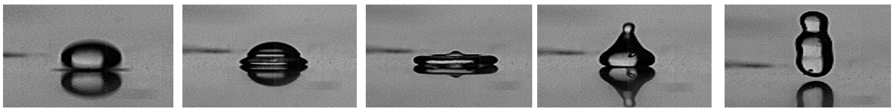
RESULTS AND DISCUSSION

Fig. 2 shows the visualization images of water droplet impinging into the plate without heating. Due to the hydrophilic nature of the aluminium plate, droplet impinges to the plate then spread followed by recoiling. We did not observe any rebound phenomenon in case of cold plate impingement experiment. However, Fig. 3 demonstrates quite different phenomenon at the same Weber number case. When the droplet impinged to the hot surface, rebound of droplet has happened due to Leidenfrost phenomenon. At the room temperature condition, the aluminium plate has hydrophilic nature, however, the surface behaviors super hydrophobic nature. Fig. 4 depicts droplet impingement behaviour at the case of high Weber number. When droplet impinged onto the hot surface, droplet spreads with fingers widely due to high momentum. The fingers were recoiled but made many droplets then rebounded. In general, we observed three different behaviours of droplet dynamics with respect to different Weber numbers. First, droplet showed just rebound when the Weber number was less than 30. The second case was that droplets spread before rebound when the Weber number was between 30 and 80. The last case was that droplet shows splash behaviour when the Weber number was higher than 80.



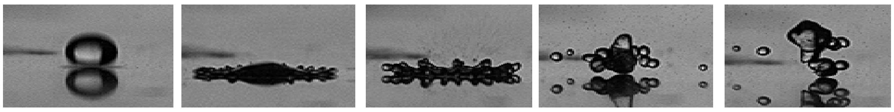
0 ms 1 ms 2.75 ms 6.75 ms 12 ms

Figure 2 Water droplet impinging on 25ºC aluminum plate (We = 4.98)



0 ms 1 ms 2.75 ms 6.75 ms 12 ms

Figure 3 Water droplet impinging on 300ºC aluminum plate (We = 4.98)



0 ms 1 ms 2.75 ms 6.75 ms 12 ms

Figure 4 Water droplet impinging on 300ºC aluminum plate (We = 117.54)

CONCLUSIONS

The dynamic behaviour of the droplet impingement onto a plate with and without heating was investigated. The parameters adopted were Weber number and temperature of the aluminium plate. Droplet falls onto the aluminium plate at room temperature only to be oscillatory motion and then sticks on the plate with some energy consumption. On the other hand, when the droplet falls onto the high temperatures plate (300℃), it was bumped against by the plate. In case of Weber number is less than 30, droplet rebounded on surface at that time of spherical shape, it occurred to rebound after splash phenomenon at between 30 and 80. Last, when droplet impinged on surface, it behaves shape of crown, then it is separated a string of minute droplets and it will be able to confirm that the disappearance of rebound energy. From this research, we found the critical Weber number for splashing condition was 80. When Weber number is less than 30, droplet is occurred to only rebound. Weber number is between 30 and 80, it seemed to spread phenomenon before rebound. When Weber number is more than 80, droplet is seemed to splash with some of small scale droplets.

References

[1] Heng Xie, Zhiwei Zou, "A model for droplet evaporation near Leidenfrost point", 2007 International journal of heat and mass transfer, Vol.50, Issues.25-26, pp.5328-5333.

[2] D Chatzikyriakou, S P Walker, C P Hale and G F Hewitt, "The measurement of heat transfer from hot surfaces to non-wetting droplets", 2011 International journal of heat and mass transfer, Vol.54 No.7/8, pp.1432-1440

[3] Darin Corneau, Kevin Latourette and John Pate, "The effect of Weber number and spread factor of a water droplet imping on a super-hydrophobic substrate", 2007 Applied Mathematic

[4] Michael A, Nilsson, Jonathan P and Rothstein, "The effect of contact angle hysteresis on droplet coalescence and mixing", 2011 Journal of colloid and interface science, Vol.363 No.2, pp.646-654