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Visual Studies on Film Boiling

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***Abstract* - The purpose of this research is to study and examine the droplet bounding phenomena on carbon heated surface during film-boiling period, which occur when a water droplet collided with the heated surface at a very high temperature (400ºC-500ºC). When the surface temperature reaches a maximum value, the critical superheated surface is suddenly covered with a vapor layer. Because of the vapor layer's lower thermal conductivity, this vapor layer insulates the surface. This condition of vapor film insulating the surface from the liquid characterizes film-boiling. The carbon boiling curve that obtained from the experiment is examined in order to study the relation between carbon boiling curve and the evaporation lifetime curve of a droplet. According to the Leidenfrost phenomena, liquids cannot touch a surface with a temperature above their boiling point because evaporation forms a cushion of vapor preventing contact. The higher the surface's temperature above the boiling point of the liquid, the more rapid evaporation occurs. The carbon material was heated in order to study this bounding phenomenon in the droplet collision boiling system.**

***Keywords*- Film boiling, Droplet, Heated surface**

I. INTRODUCTION

Unlike bubble generation from the cavity of the solid heating surface, large numbers of minute bubbles are generated in a liquid layer by the spontaneous nucleation, when the liquid layer, which contacted the heated surface, is rapidly heated. The spontaneous nucleation boiling is also called fluctuation nucleation. Existence of this fluctuation nucleation boiling phenomenon and the generation behavior are found by Skripov et al. [1], and afterwards it has been clarified by many researches, Baumeister, K . J ., and Simon, F.F [2], Inada and Yang [3].These research focused on the fact that the fluctuation nucleation boiling is generated at the moment when a water droplet collides with the solid surface heated at the fixed temperature. At this time, the boiling phenomenon, in which large number of minute liquid particles intensely scatters to the atmosphere, namely the miniaturization-boiling phenomenon named by Inada and Yang [4], was observed. This research is based on the idea that the minute bubble generated by the fluctuation nucleation boiling, namely the micro-bubble brings about the intense dispersion of the droplet. Then, the surface material was heated in order to catch the micro-bubble, and the behavior on the solid-liquid interface at the moment of the droplet collision was photographed from the horizontal direction by using a high speed camera. In this study, focusing on the range of the heating surface temperature (160ºC - 420ºC), namely the range from the vicinity of the maximum boiling rate point of the droplet up to the film boiling, the liquid-solid contact behavior on the heating surface was caught. In this research, we focus on film boiling phenomena that occurred at high temperature on material heated surface. From the received data, the unique bounding phenomena of the droplet on the carbon heated surface was examined.

II. EXPERIMENTAL APPARATUS

1: High speed video camera
2: Main memory
3: TV monitor
4: TV monitor controller
5: Computer
6: Pen recorder
7: Degassed and distilled water
8: Circulating water at constant temperature
9: Halogen lamp
10: Droplet
11: Shutter
12: Cartridge heater
13: Thermocouple
14: Material disc

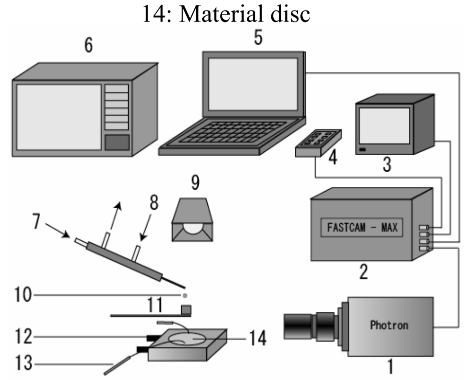


Figure 1: Experimental Apparatus

Figure 1 illustrates a schematic of the experimental apparatus. The heating surface is a disk of 30mm diameter and 8mm height, and it is retained levelly and is heated from its periphery by an electric cartridge-type heater. Degassed and distilled water was used as a droplet. The water droplet diameter was retained 4.0mm, and falling height was kept at 65mm. This height is in the range that the droplet itself does not disintegrate by the collision energy of the droplet.

The temperature of the droplet was kept at 16ºC by the circulation of the tab water in the circumference of the nozzle. The temperature of the heating surface was measured by attaching the thermocouples with ceramic adhesive at two points on the surface. The droplet bounding phenomena was photographed in real time and was recorded by a frame rate at 10,000 fps with 1/10,000 shutter speeds.

III. RESULT AND DISCUSSION

Figure 2 shows the droplet boiling behavior on carbon heated surface at the temperature of 140ºC. From the experiment, it is observed that the nucleate boiling occurred at the temperature of 120ºC, 140ºC and 160ºC on carbon heated surface. The captured image shows that a weak nucleation boiling occurred on carbon heated surface. The droplet begins to form a hat shape during 2.0ms and it becomes flat on the surface during 6.0ms up to 10.0ms. This phenomenon continues and the droplet begins to form a mountain shape at about 19.0ms and this phenomenon continues long as shown in Fig. 2. During the experiment, it is also observed that only nucleate and film boiling occurred on carbon heated surface which also have the smallest thermal property value among all the materials used in the experiment. The thermal property value for carbon material is 0.6029 x 10-4 [Ws1/2/m2K]. Figure 3 shows the droplet boiling behavior on carbon heated surface at the temperature of 260ºC. At this period, it is observed that the film boiling begins to take place on carbon heated surface. From the captured image, it is observed that droplet bounding phenomena begins at 15ms and continue until 43ms when the droplet touches the heated surface again. This phenomenon continues about 28ms above the carbon heated surface. Although the film boiling has already started, a weak dispersion from the mother droplet still occurs which means that the film boiling is still not in perfect condition. Figure 4 shows the droplet bounding phenomena on carbon heated surface at the temperature of 420˚C.

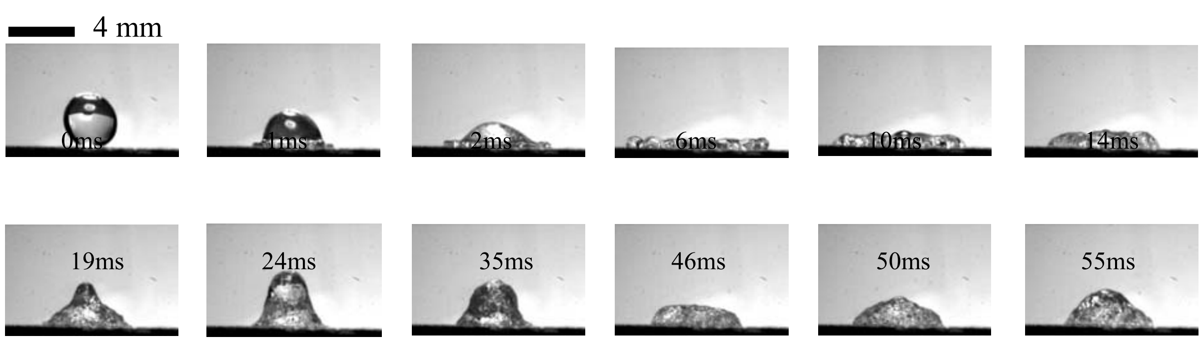


Figure 2: Nucleate boiling phenomena on carbon heated surface at the temperature of 140˚C

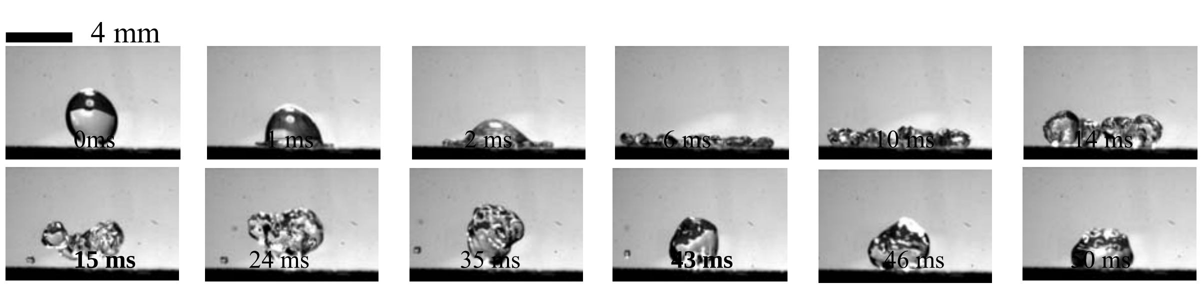


Figure 3: Film boiling phenomena on carbon heated surface at the temperature of 260˚C

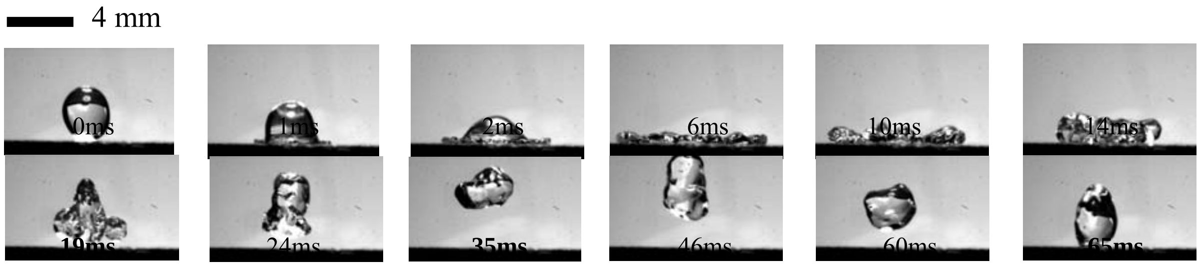
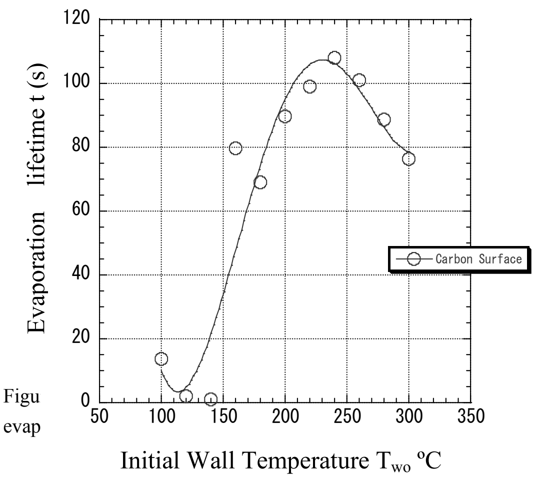


Figure 4: Film boiling phenomena on carbon heated surface at the temperature of 420˚C

The numerical value shown under each photograph is the elapsed time after the droplet collision. When the surface temperature reaches a maximum value, the critical superheated, vapor begins to form faster than liquid can reach the surface. Thus, the heated surface suddenly becomes covered with a vapor layer. Because of the vapor layer's lower thermal conductivity, this vapor layer insulates the surface. This condition of vapor film insulating the surface from the liquid characterizes film boiling. From Figure 4, it is observed that the droplet begins to bounds at 19.0ms and continues to float up in the air until 65ms when the droplet once again touches the surface. This means that the droplet floating phenomena on the carbon heated surface continues at about 46.0ms as shown in Figure 4. The highest level of droplet bounding height occurred at 35.0ms on carbon heated surface at the temperature of 420ºC (3mm). This bounding phenomena on heated surface is highly caused by the vapor pressure that released from the hot surface. A high vapor pressure is produced when the droplet approaches to the hot surface. This bounding phenomena of the droplet is largely due to the large repulsive force produced by the vapor pressure from the hot surface. From Figure 4, we assumed that the vapor layer has been generated on the heating surface. During this period, the droplet floats on a vapor cushion and the droplet has no direct contact with the heating surface. Figure 5 shows the relation between temperature change and droplet evaporation lifetime curve of carbon heated surface. From Figure 5, it is observed that a week nucleation boiling continues from 120ºC up to 220ºC on carbon heated surface. The graph starts to fall down when the temperature reach 260ºC which means that the film boiling phenomena begins to take place. We can clearly see the captured image during this film boiling period from the image shown in Figure 4. The numerical value shown under each photograph is the elapsed time after the droplet collision on carbon heated surface.



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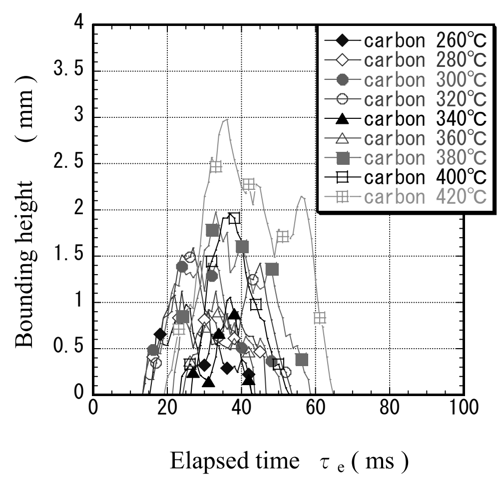

Figure 6: Relation between elapsed time and bounding height on carbon heated surface

Figure 6 shows the relation between elapsed time and bounding height that occurred on carbon heated surface. From Figure 6, it is observed that the film boiling phenomena begins at the temperature of 260ºC on carbon heated surface. From the graph also, it is observed that the bounding phenomena begins from 260ºC and continues until the surface reaches the temperature of 420ºC. From the graph, it is observed that, the bounding phenomena took place at almost all temperatures (260ºC-420ºC). From Figure 6, it is observed that the maximum bounding height that occurred on carbon heated surface is about 3mm at the temperature of 420ºC. The droplet shape changes spontaneously due to the free vibration period of the droplet. The droplet shape movements and changes during the experiment can be observed through the captured image as shown in figure 4.

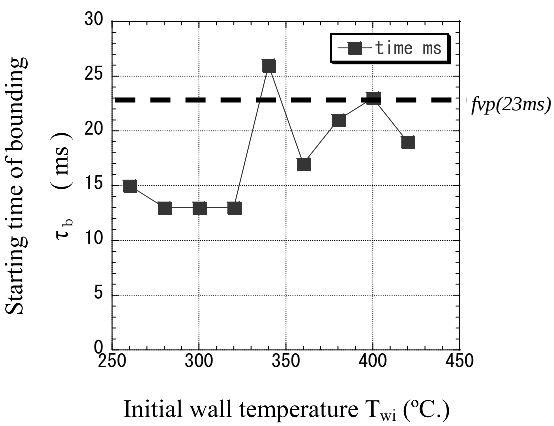

Figure 7: Relation between initial wall temperature and starting time of droplet bounding on carbon heated surface.

Figure 7 shows the relation between initial wall temperature and starting time of droplet bounding phenomena on carbon heated surface. From Figure 7, it is observed that the starting time for droplet bounding phenomena on carbon heated surface is about 26ms at the temperature of 340ºC which is the highest time among all the temperature. The starting time of droplet bounding is 19ms at the temperature of 420ºC where the maximum bounding droplet occurred during this period as shown in figure 4. It is also observed that the starting time is same at the temperature of 280ºC, 300ºC and 320ºC that is about 15ms on carbon heated surface. From the received data, it is concluded that, even the starting time is different for all temperature, it also shows that the starting time of droplet bounding phenomena agrees closely to the theoretical value of the free vibration period of a droplet.

IV. CONCLUSIONS

1) The highest maximum bounding height occurred on carbon heated surface at the temperature of 420ºC.
2) The starting time for droplet bounding phenomena on carbon heated surface agrees closely with theoretical value of free vibration period of the droplet.

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