Proceedings of the
International Conference on Mechanical Engineering 2011
(ICME2011) 18-20 December 2011, Dhaka, Bangladesh

ICME11-TH-007

INVESTIGATION OF DROPLET EVAPORATION PHENOMENA OVER A HOT SURFACE

Mohammad Mezbah Uddin[1], **Koji Okamoto**[2], **Manabu Tange**[2] **and Someya Satoshi**[2]

[1]Reactor Operation and Maintenance Unit, Bangladesh Atomic Energy Commission , Bangladesh
[2]Department of Human and Engineered Environmental Studies, The University of Tokyo, Japan.

ABSTRACT

A liquid droplet evaporation is very important considering various types of combustion engines, cooling systems as well as many fire safety situations. In this paper, droplet evaporation lifetime phenomena for heated Zircaloy and Titanium surfaces are investigated. It has been observed that heated Zircaloy and Titanium surfaces showed almost similar evaporation lifetime phenomena up to nucleate boiling regime. But in the transition and film boiling regime, evaporation lifetime for single droplet is very much higher for Titanium surface compare to Zircaloy surface. It has been also observed that effect of UV light on Titanium surface is prominent rather than Zircaloy surface considering contact angle. Heating and boiling have strong effect on contact angle that strongly enhances droplet evaporation lifetime for the Zircaloy surface.

Keywords: Droplet Evaporation Lifetime, Film Boiling, UV Light , Contact Angle

1. INTRODUCTION

The first observation of the behavior of a droplet levitated over a hot, horizontal surface was reported by Leidenfrost in 1756 and hence the behavior is known as the Leidenfrost phenomenon. However, a systematic study of the phenomenon began much later with Tamura and Tanasawa [1].

They measured the evaporation lifetime of liquid droplets levitated over a hot surface at atmospheric pressure. As shown in fig: 1, they classified the dynamics and heat transfer of droplet evaporation into four regimes: film evaporation (a-b), nucleate boiling (b-c), transition (c-d) and spheroidal vaporization (>d). The temperature at point b is the boiling temperature and at point d the Leidenfrost temperature, where the heat transfer reaches a local minimum. Of particular interest is point c where heat transfer is maximum. Since then much progress has been made in extending the work [2-4].These include experimental studies, as well as theoretical and numerical analyses on the effect of ambient pressure, types of liquids, surface conditions (roughness, temperature and material) and initial drop sizes.

In all of the previous experimental studies, the impinging droplets were produced by a hypodermic syringe. Therefore, the droplet diameters were, in general ,larger than 1 mm, which is much larger than the typical droplets in sprays. Because there exists significant effects of droplet sizes on the dynamics and thereby the thermo chemistry of a droplet impinging on a hot surface, applications of results obtained for larger droplets are limited.

The objective of the present study is to focus on droplet evaporation lifetime for various materials considering UV light、heating and boiling effect.

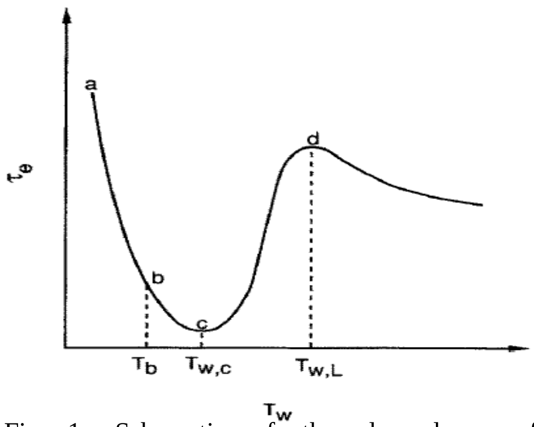


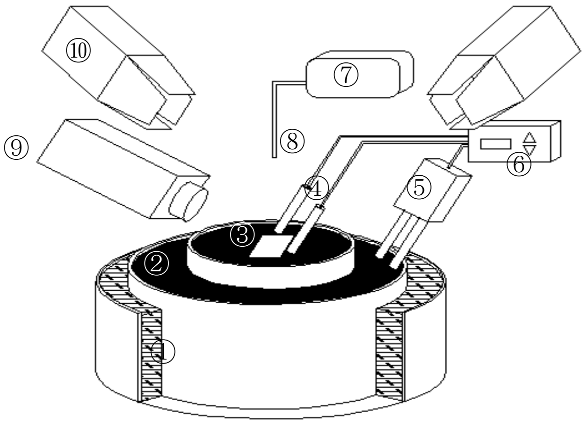
Fig 1. Schematic of the dependence of evaporation lifetime of a droplet on hot surface

2. EXPERIMENTAL SET UP AND PARAMETERS

2.1 Set UP

Figure 1 shows the schematic of the experimental setup. The heated specimen plate is a SUS304 plate, kept on liquid metal (U-alloy of Ti, Cd, In & Sb, MP =138^0 C). The liquid metal was heated by an electric heater (500 W) and the temperature was controlled with a controller connected with the heater and a thermocouple. A micro syringe pump was used to generate droplet. The drop diameter for all cases was about 3 mm. The other information of the set up is shown in Fig. 1.

The drop spreading dynamics are captured at 30,000 frames per second using a Photron High Speed Camera. Image processing and the corresponding data analysis are accomplished using Photron High Speed Camera software.



1: Insulator 2: U-Alloy 3: Test piece 4: Thermocouple 5: Heater 6: Temperature controller 7: Micro syringe pump 8: Nozzle 9: High speed camera 10: Light source

Fig 2. Experimental apparatus

2.２ Experimental Parameters

The first step in our experiment was to prepare Titanium and Zircaloy surface. Pure water and alcohol were used as liquid. Titanium and Zircaloy surfaces are irradiated for 24 hours using UV light with intensity 34 mW/cm$^{2.}$ This UV irradiation was performed in order to check the surface wettability change of Titanium and Zircaloy surface. Few test pieces are heated for 3 to 4 hours and other test pieces are heated for different temperatures and sprayed water droplet on the heated surfaces. Both of these categories test pieces are analyzed considering surface wettability

2.3 Droplet Evaporation Time Measurement

In order to measure the droplet evaporation time, two stop watches were used. It is to be mentioned that for very short time phenomenon, droplet and heated surface interactions are captured at 30,000 frames per second using Photron High Speed Camera

2.4 Contact Angle Measurement

The main parameter used in this experiment is contact angle. Contact angle was measured for different conditions. In this measurement the contact angle photograph was captured using High Speed camera. Before capturing the photographs, a photograph of known dimension metal wire was taken. Then the length of the wire was measured in terms of pixels. And then the relation between pixel and cm was established in order to measure the length of the contacted droplet diameter and height. And finally contact angle was measured using young equation. It is to be mentioned that these measurements are performed using Photron High Speed Camera software.

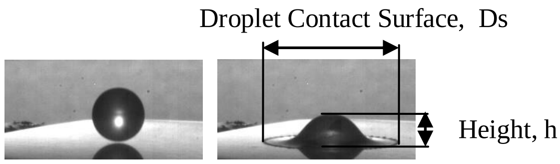


Fig 3. Drop Contact Angle

3. RESULTS AND DISCUSSIONS

The evaporation modes of a liquid droplet impinging on a hot surface have been investigated and droplet lifetime, contact angles have been measured. The parameters that effect the droplet evaporation lifetime and contact angle are described below:

3.1 Effect of Wall Temperature and Surface Material on Droplet Evaporation Time

Figure 4 shows typical experimental results of the evaporation lifetime of Zircaloy and Titanium surface, as a function of wall temperature. There shows a big difference for the droplet lifetime of Titanium and Zircaloy surface. For the Titanium surface droplet lifetime is higher than the Zircaloy surface and Leidenfrost phenomena occurs at a early temperatures for Titanium surface. But in case of Zircaloy surface nucleate boiling continues up to a higher temperatures as a consequence Leidenfrost phenomena occurs at a higher temperature. The highest temperatures for which droplet lifetime are the highest for Titanium and Zircaloy surfaces are 230 and 300 ^{0}C respectively.

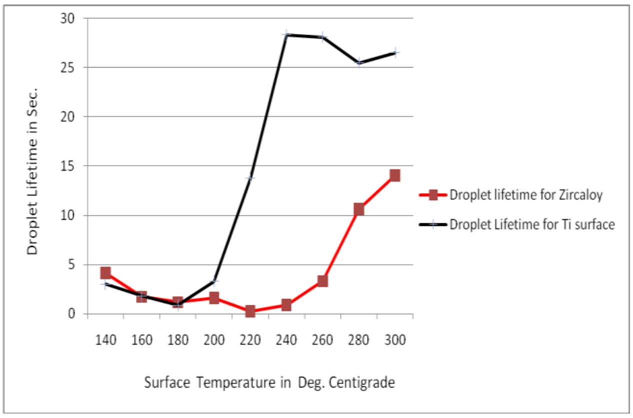


Fig 4. Droplet Lifetime, t (Sec.) Vs. Surface Temperature (^{0}C) Graph

3.2 Compare the Effect of Wall Temperatures and Surface Materials on Droplet Evaporation Time with other Researchers Work

The average lifetime of droplet for different surfaces are shown in the Figure 5. From the figure it is clear that Titanium surface lifetime has similar trend with the graph of Y. M. Qio et al. [5]. The referred graph was for water; diameter of the droplet was 2 mm and the test piece was stainless steel. But the graph does not show relevancy for Zircaloy surface. So it can be concluded that Zircaloy surface showed very good heat transfer characteristics up to 255 deg centigrade and after this temperature DNB starts comparing Titanium and SS surface.

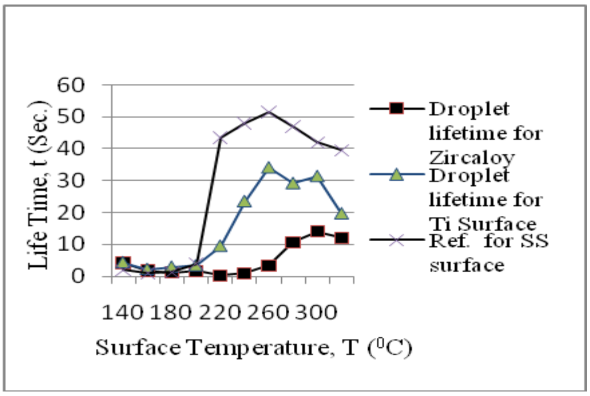


Fig 5. Droplet Lifetime,t (Sec.) Vs. Surface Temperature (^{0}C) Graph

3.3 Effect of UV light on Droplet Lifetime for Ti Surface

From the Figure 6 it is seen that for pure Titanium surface, droplet lifetime is higher compare to the UV irradiated titanium surface for all surface temperatures. Nucleate boiling occurs at lower temperatures and Leidenfrost phenomena occurred at early temperatures. But in case of 24 hr UV irradiation (34mW^2) of Ti-surface the trend of droplet lifetime is similar to the pure Ti- surface but lifetime reduces slightly up to a higher temperatures and as a consequence Leidenfrost phenomena occurs at a higher temperature.

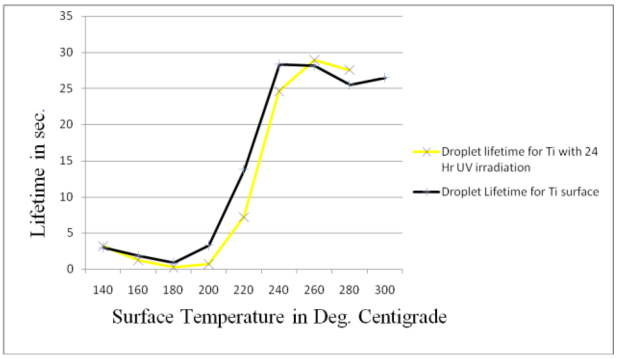


Fig 6. Droplet Average Lifetime,t (Sec.) Vs. Surface Temperature in Deg. Centigrade for Titanium

3.4 Effect of UV light, Heating and Boiling on Contact Angle for Titanium Surface

UV effect, heating effect and heating and boiling combined effect on Titanium surfaces are examined. As contact angle is a measure of surface wettability, it is measured for Titanium surface. It is observed that effect of UV light on Titanium surface was less but there were big combined effect of heating and boiling on the contact angle of Titanium surface.

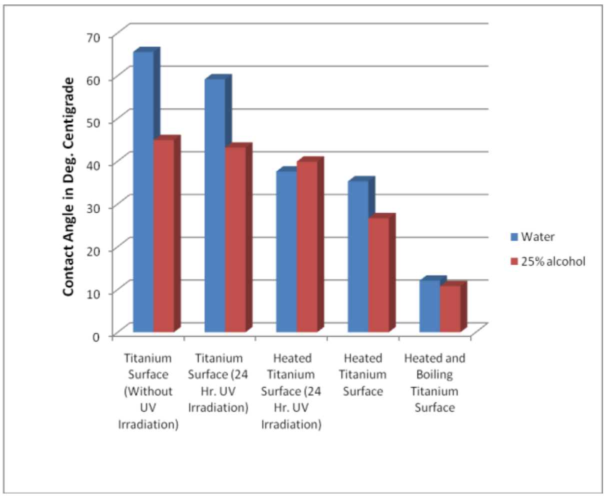


Fig 7. Contact angle for Titanium surface

From the Figure 7 it is seen that contact angle decreases when the Titanium surface is irradiated with UV light. It also shows water and 25% alcohol mixture for every case. It is clear that in every case contact angle is lower for alcohol cases. But the contact angle decreased a lot when the test surface is heated and boiled.

time reduces a lot and test surfaces showed very good heat transfer characteristics.

3.5 Effect of UV light, Heating and Boiling on Contact Angle of Zircaloy Surface

Contact angle is measured for Zircaloy surface and UV effect, heating effect and heating and boiling combined effect on Zircaloy surface are examined. It is observed that effect of UV light on Zircaloy surface was little bit hydrophobic because the contact angle slightly increases after UV irradiation. But there was big combined effect of heating and boiling on the surface wettability of Zircaloy surface. Because when the Zircaloy surface is treated with heating and boiling, contact angle decreases drastically and it becomes almost zero.

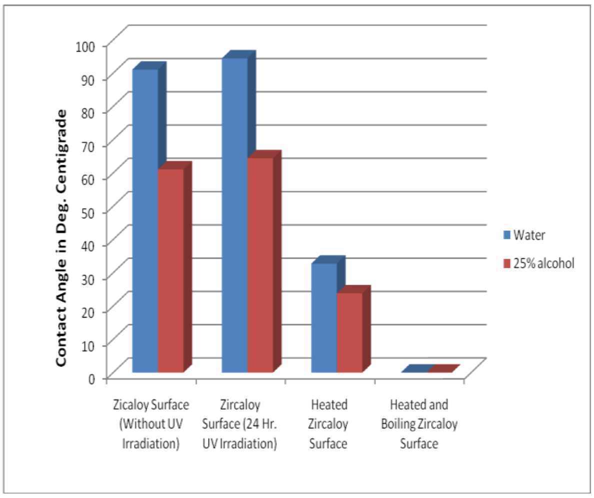


Fig 8. Contact angle for Zircaloy Surface

It is observed that UV light has little effect on Titanium surface but for Zircaloy surface it has very little reverse effect. But heating and boiling has strong combined effect for Titanium and Zircaloy surface and for Zircaloy surface it is very much prominent.

4. CONCLUSION

Droplet evaporation lifetime for Titanium surface and Zircaloy surface showed similar tendency up to nucleate boiling regime. But it is very much higher in the Transition and Film boiling regime for Titanium surface compare to Zircaloy surface. So, Leidenfrost phenomena occurs at a early temperature for Titanium surface compare to Zircaloy surface. As a Consequence, Zircaloy surface showed good heat transfer characteristics in the transition and film boiling regime.

The UV light has little effect on the surface wettability of the Titanium surface but for Zircaloy surface it has little bit reverse effect. The UV light slightly increases the contact angle of the Zircaloy surface; it makes the Zircaloy surface hydrophobic state. The heating and combined effect of boiling and heating significantly change the surface wettability of the Titanium and Zircaloy surface. The heated and boiled (quenched) surface for Titanium and Zircaloy achieved strong hydrophilic state. As a result heat transfer area under the droplet increased a lot consequently droplet evaporation

5. ACKNOWLEDGEMENT

The research work has been performed in the Visualization Laboratory, Institute of Environmental Studies, The University of Tokyo, Japan. The author expresses strong gratitude to Asian Development Bank (ADB), Bangladesh Atomic Energy Commission and The University of Tokyo, Japan for arranging fund and opportunity.

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7. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(**^{0}C**)
t	Life time	(Sec.)
UV	Ultraviolet Ray	(mW/cm2)

8. MAILING ADDRESS

Mohammad Mezbah Uddin
Reactor Operation And Maintenance Unit
Atomic Energy Research Establishment
Bangladesh Atomic Energy Commission (BAEC)
Ashulia, P.O. DEPZ-1349, Savar, Dhaka, Bangladesh
Phone: +8801711364769
E-mail: mrmezbah38@yahoo.com