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INVESTIGATION OF SURFACE WETTABILITY AND DROPLET EVAPORATION DURING DROPLET AND HOT SURFACE INTERACTION CONSIDERING UV LIGHT AND BOILING EFFECT

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Abstract- *During the interaction between droplet and heated surface, a liquid droplet evaporation is very important considering various types of combustion engines, cooling systems as well as many fire safety situations. Here we identify that Zircaloy and Titanium surfaces showed different lifetime phenomena after* 200^0C *temperature. It has been observed that Titanium surface lifetime increases drastically after* 200^0C *but for Zircaloy surface it increases very smoothly. It has been also observed that contact angle which is a measure of surface wettability is strongly affected by UV light, heating and boiling. The effect of UV light on Titanium surface is prominent rather than Zircaloy surface. Heating and boiling have strong effect on contact angle that strongly enhances the heat transfer of the Zircaloy surface.*

Keywords: Surface Wettability, Life Time, Contact Angle, Heating and Boiling, UV Light

1. INTRODUCTION

The evaporation and ignition of liquid droplets impinging on a hot surface are of interest in a number of areas related to various types of combustion engines, cooling systems as well as many fire safety situations. In all of the above applications, the dynamic behavior of the impinging droplets, the heat and mass transfer between droplets and the hot surface, and the ignition characteristics of fuel droplets are important phenomena requiring fundamental investigations.

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].

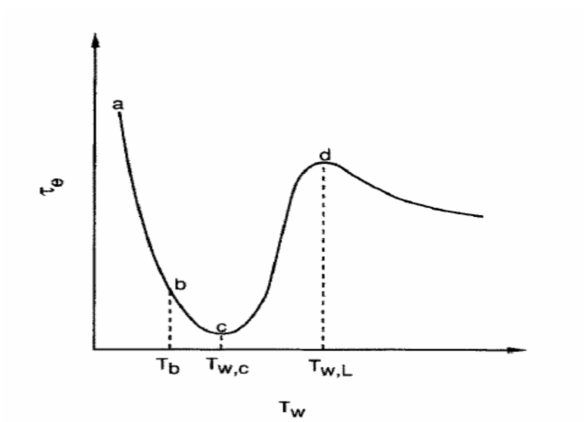


Fig. 1 Schematic of the dependence of evaporation lifetime of a droplet on hot surface

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 of ref. [1] (e.g. see refs. [2-5]).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.

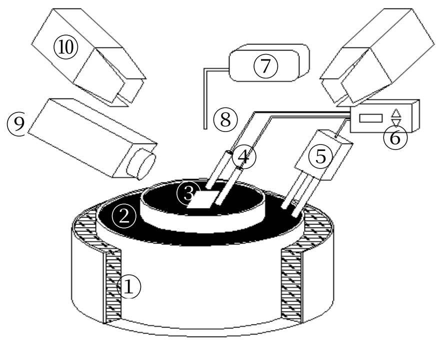
In all of the previous experimental studies, the impinging droplets were produced by a hypodermic syringe. Therefore, the droplet diameters were, in general, larger than 1 mm, which is much larger than the typical droplets in sprays. Because there exists significant effects of droplet sizes on the dynamics and thereby the thermochemistry 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 droplets lifetime for various materials and also analyze the UV light、heating and boiling effect on surface wettability of different materials as a measure of droplet contact angle.

2.1 Experimental 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 of 34mW/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 Lifetime Measurement

In order to measure the droplet lifetime, 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.

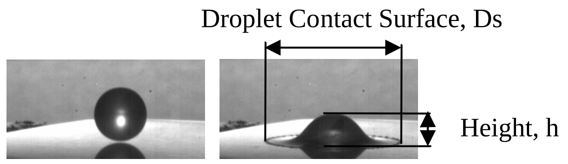


Fig. 3 Drop Contact Angle

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 contact angle and lifetime are described below:

3.1 Effect of Wall Temperature and Surface Material on Droplet Lifetime

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 an early temperatures for Titanium surface. But in case of Zircaloy surface, nucleate boiling continues up to 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.

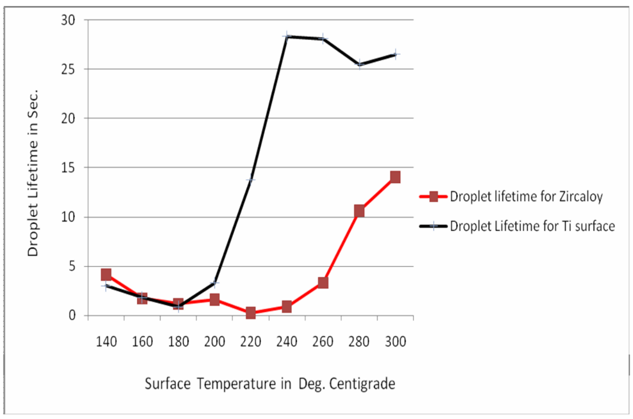


Fig 4: Droplet Lifetime, t (Sec.) Vs. Surface Temperature (^{0}C) Graph

3.2 Compare the Effect of Wall Temperatures and Surface Materials on Droplet Lifetime 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. [6]. 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.

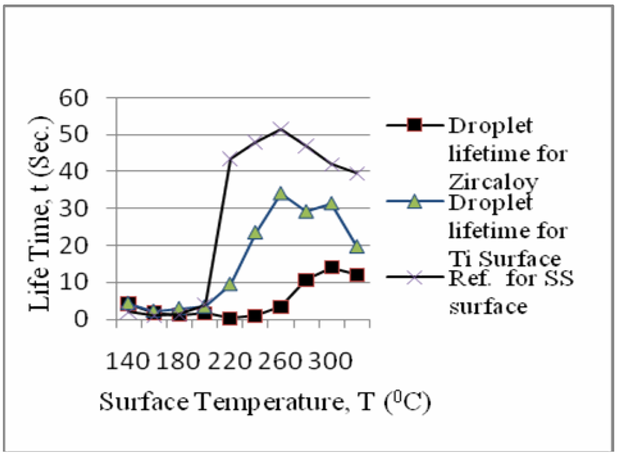


Fig 5: Droplet Lifetime,t (Sec.) Vs. Surface Temperature (^{0}C) Graph

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 upto a higher temperatures and as a consequence Leidenfrost phenomena occurs at a higher temperature.

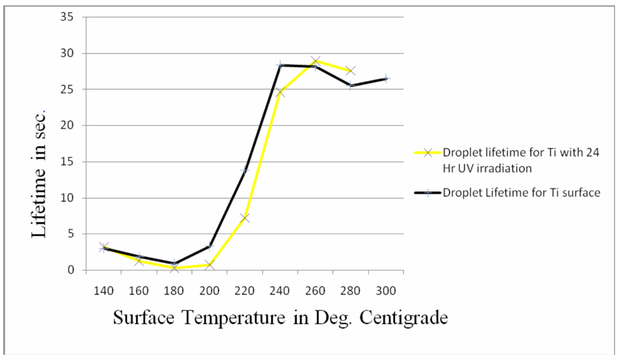


Fig 6: Droplet Average Lifetime, t (Sec.) Vs. Surface Temperature in Deg. Centigrade

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.

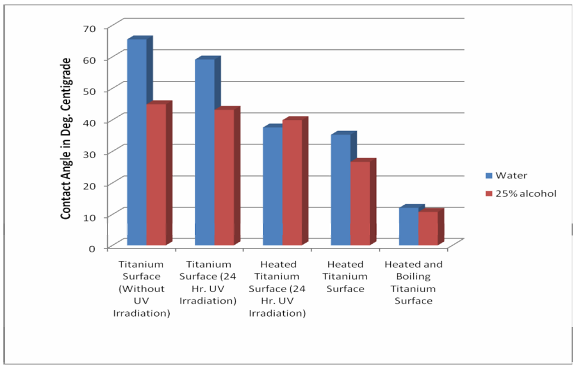


Fig 7: Contact angle for Titanium surface

From the Figure 7 it is seen that contact angle decreases when the Titanium surface is irradiated with UV light. It 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. The average contact angle for the Titanium surface for five different conditions is given in Table 1.

3.5 Effect of UV light, Heating and Boiling on Surface Wettability 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.

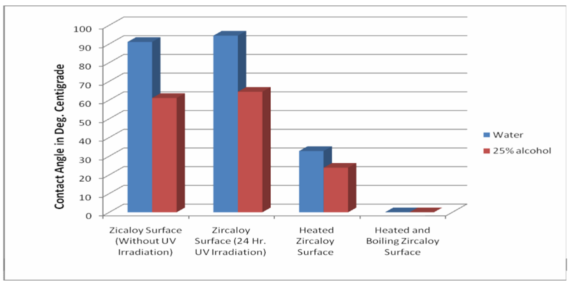


Fig 8: Contact angle for Zircaloy

From the Table 1 & 2 it is observed that contact angle changed a lot for different surface conditions of Zircaloy and Titanium surfaces. For Titanium surface contact angle decreases 10.8% for UV effect, 46.2% for heating effect and 81.6% for heating and boiling combined effect considering water but for alcohol cases contact angle decreased a lot in every cases.

For Zircaloy surface contact angle increases 3.7% for UV irradiation but in case of heated Zircaloy surface contact angle decreases 64.03% and in case of heating and boiling combined effect, Zircaloy surface contact angle becomes zero. The decreasing and increasing trend for Zircaloy surface and Titanium surface is almost similar for 25% alcohol and water mixture. But in the case of alcohol mixture, contact angle decreased a lot comparing water.

It is also observed that UV light has strong 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.

Now the question is why contact angle decreases for heated Titanium and Zircaloy surface and became almost zero for boiling and heating surface?

From the heating and boiling of the Zircaloy and Titanium surface, surface roughness changed a lot. The primary cause for surface roughness was determined to be a hydrogen diffusion phenomenon resulting from breakdown of water vapour at high temperatures.

The earliest known boiling enhancement studies by Jacob and Fritz and by Sauer pointed to rapid deterioration of the boiling enhancement with time, due to changes in both surface roughness and surface chemistry.

It is to be mentioned that all boiling regimes are not equally impacted by surface roughness. Direct access of the liquid to the surface during nucleate boiling renders this boiling regime most sensitive to microsurface geometry. Liquid access is much more limited during the transition boiling regime due to an intermittent vapor blanket between the liquid and the surface, rendering any surface roughness features which are smaller than the thickness of the vapor film ineffective at promoting nucleation.

Table 1: Contact angle for Titanium surface for different surface conditions

Test Piece	Surface Condition	Contact Angle in Deg. Cent. (*)	Contact Angle in Deg. Cent. (**)	Remarks
Titanium Surface	Without UV irradiation	65.53	44.94	Surface tension effect
Titanium Surface with UV light	UV irradiation for 24 hours, Intensity 34mw/cm 2	59.14	43.17	UV effect
Heated Titanium Surface and UV irradiation	UV irradiation for 24 hours, Intensity 34 mw/ cm2	37.59	39.9	UV & Heating Effect
Heated Titanium Surface	(Temp. was 140-300 deg. cent. for 5 hours)	35.28	26.67	Heating Effect
Heating and Boiling of Titanium Surface	Temp. was 140-300 deg. cent. for 5 hours and water droplet was sprayed at every 20 deg. Cent. interval	12.06	10.77	Heating & Boiling Effect

* water is used, ** 25% Alcohol and Water mixture is used

Table 2: Contact angle for Zircaloy surface at various surface conditions

Test Piece	Condition	Contact Angle in Deg. Cent. (*)	Contact angle in Deg. Cent. (**)	Remarks
Pure Zircaloy Surface	Without UV irradiation	91.08	61.09	Surface tension effect
Zircaloy Surface with UV Irradiation	UV irradiation for 24 hours, Intensity 34 mw/cm2	94.45	64.45	UV effect
Heated Zircaloy Surface	(Temp. was 140-300 deg. cent. for 5 hours)	32.76	23.84	Heating Effect
Heating and Boiling of Zircaloy Surface	Temp. was 140-300 deg. Cent. for 5 hours and water droplet was sprayed at every 20 deg. Cent. interval	0	0	Heating & Boiling Effect

4. CONCLUSIONS

Droplet lifetime for Titanium surface is higher compare to Zircaloy surface. As a result Leidenfrost phenomena occurs at a early temperature for Zircaloy surface compare to Titanium surface and Zircaloy surface showed good heat transfer characteristics.

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 both boiling and heating combined effect significantly change the surface wettability of the Titanium and Zircaloy surface. The heated and boiled (quenched) surface for Titanium and Zircaloy achieved hydrophilic state.

The UV effect on Titanium surface is temporary and after few days later the surface loses its UV irradiation effect. The humidity effect on the measurement of surface wettability has not been examined. The humidity effect should calculate considering the lab environment.

5. REFERENCES

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6. NOMENCLATURE

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