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VISUALIZATION OF TRANSIENT INTERACTION PHENOMENA BETWEEN DROPLETS AND HOT WALLS AROUND LEIDENFROST TEMPERATURE FOR SUS304

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ABSTRACT

The visualization of transient interaction phenomenon of one drop impinging on a hot surface by varying the surface temperature, the drop velocity at a temperature below and above the Leidenfrost temperature has been experimentally evaluated. In this experiment specially droplet interaction behavior in respect to the different drop velocity was analyzed with high speed camera using 3000 frames per second. A large influence on the Leidenfrost phenomenon of SUS304 was determined and it has been observed that with higher drop velocity, Leidenfrost temperature decreases. At a certain drop velocity and surface temperature, droplet jet extraction phenomenon has been discovered. Because of the vaporization at the first impact of the droplet bottom, the vapor migrated from the bottom of the droplet to the top of the droplet and then the jet has been extracted from the top of the droplet. At higher drop velocity, the jet extraction phenomenon does not occur, since the droplet has higher impact moment. The other factors that affect the jet extraction phenomenon is surface temperature and surface roughness. Surface roughness has to be considered the prime factor for jet extraction phenomenon.

Keywords: Transient Interaction, Leidenfrost Temperature, Jet Extraction

1. INTRODUCTION

Transient interaction phenomena between droplets and hot walls is a very important phenomenon. Hot surface rewetting is of great interest in metallurgy, in electronics systems and in nuclear reactor safety, for which has been extensively studied in the past. Spray cooling of hot metals in steel industries represents another important application for interactions between droplets and hot walls. The knowledge of the phenomenology associated with the heat transfer between the liquid and the overheated wall is fundamental to the accident cooling management and its safeguard in favour of the possible people who by chance may be involved in the accident.

Besides these, two-phase flows containing droplets carried by a gas are quite common in nature and engineering. Examples are clouds droplets, fuel droplets in combustion process and inhalation of medical sprays etc. For a better understanding of such systems the investigation of the involved elementary process is important. In recent years interactions between droplets and hot walls have been investigated in detail by many researchers as these process have also considerable influence on two-phase flows [1-4].

The interaction between droplets and hot walls depends mainly on the wall temperature and on the impact energy. There are two essentially different regimes for droplet wall interactions, which are separated by the Leidenfrost temperature [5]. In the regime below the Leidenfrost temperature, the interaction between a droplet and a wall depends strongly on the wall temperature and on the impact energy. In the regime above the Leidenfrost temperature the interaction process is governed by the impact energy, whereas the influence of the surface temperature on the interaction is negligible [5-8].

The existence and characterization of the Leidenfrost temperature has been widely investigated [6-7]. It depends on the solid roughness [8], on the purity of the liquid [9], on the way the liquid is deposited [10], drop velocity and surface inclination [11]. The existence of droplet torus and elongation phenomena is also investigated [12].

We focus here on other aspects of the Leidenfrost phenomenon, such as visualization of the droplet jet extraction around Leidenfrost phenomenon with high speed camera using 3000 frames per second. SUS 304 was used as test specimen. Using the advanced high-spatial resolution and high-temporal-resolution camera, more detail phenomenon will be investigated. As an experimental parameter, the droplet velocity, surface temperature and surface roughness are taken. The visualized images show the characteristics of the droplet motion around the Leidenfrost temperature, e.g., splashing, vaporization, nucleate boiling and film boiling. Under certain condition, the droplet jet extraction phenomenon has been discovered. The model of the phenomenon has been qualitatively investigated.

2.EXPERIMENTAL SETUP AND MEASUREMENT TECHNIQUES

Fig 1. shows the schematic of the experimental setup. It mainly consists of four components: the heating base for specimen plate, the heater and temperature controller unit, the drop generator and the setup for the high-speed video recording.

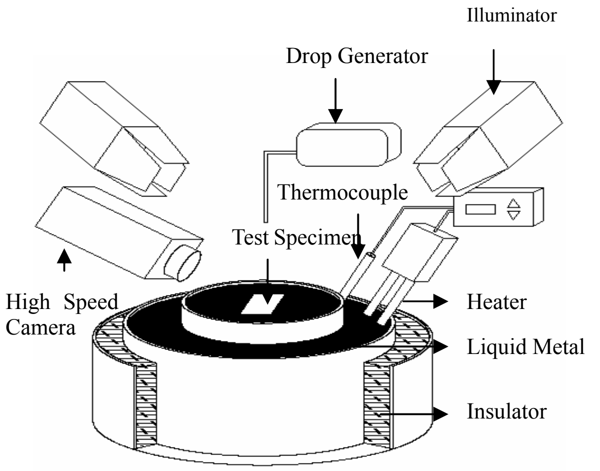

Fig 1: Schematic Diagram of Experimental Set Up

The heated specimen plate is a SUS304 plate (30X30X0.25 mm^3), kept on liquid metal (U-alloy of Ti, Cd, In & Sb, MP-138 °C). The liquid metal was heated by an electric heater (500 W). Basically the test specimen is kept in a small SS bowl and that bowl was full with liquid metal and is kept inside a big SS bowl.

One thermocouple was kept inside the liquid metal of big bowl and it was connected with the heater control circuit. For this expt. it is assumed that the test specimen temperature is same as the liquid temperature. But it has been observed that there is a temperature difference between liquid metal and test specimen which is around 5-8 °C.

The drop generator is a simple commercial syringe which was driven by a micro-syringe pump and it produces 2 mm diameter droplet. The fluid used is demineralised water at a temperature of about 25^0 C.

Movie of the drop impingement are taken with a high-speed video camera (Photron FASTCAM APX RS) at 3000 fps under 1M pixel resolution, while two electrical light of 250 W (15000 lumen) each are used as illuminator.

The test procedure is as follows:

(1) First of all the test section is heated up to the prefixed temperature, which is provided by the thermocouple placed inside the liquid metal;

(2) Then the drop is left falling on the heated plate and the movie is taken by the high-speed camerathe paper of the size 210 mm × 297 mm (A4) for typing the manuscript.

3. VISUALIZATION OF THE PHENOMENON

In this context, some picture sequences extracted from the high-speed camera are shown as a function of different parameters varied in the experiment.

In particular, Fig 2. shows pictures taken from high speed movies taken for different drop impinge velocity. Pictures are extracted from the movies with reference to 10, 30 and 50 ms, respectively, after the first contact between the drop and the surface, while the surface temperature is $T_w = 280^oC$. The impingement velocity is calculated from the falling drop theory with 15, 30 and 45 mm falling height, respectively as shown in Table 1. The corresponding Reynolds number and Weber number of the drop are also reported in the table.

The interactions greatly depend on the impingement velocity. In V= 0.54 m/s, the drop splashes and does not bounce. The drop bouncing and fragmentation are observed in higher velocity. Also the Leidenfrost temperature depends on the drop velocity. These phenomenon have similar tendency with the previous researches [11].

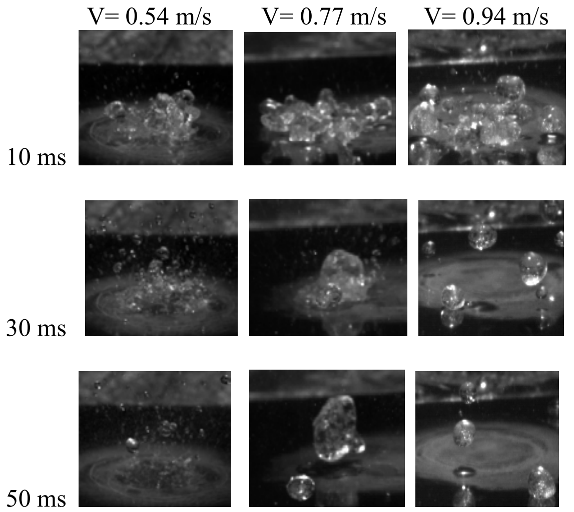

Fig 2: Comparison of boiling phenomena (10, 30 and 50 ms after the impingement with several impingement velocity under surface temperature of 280 °C).

Table 1: Calculated drop velocity at the impact on the heated surface for different drop falling height

Drop falling height (mm)	Velocity (m/s)	*Re* ($D\rho u/\mu$))	*We* ($D\rho u^2/\sigma$)
15	0.54	1084	8.4
30	0.77	1534	16.8
45	0.94	1880	25.2

Fig 3. shows the sequential impingement images with every 0.33 ms for 15 mm drop falling height (V= 0.54 m/s) and 260^0C surface temperature. In these images, the droplet jet extraction phenomenon has been observed. At the first impact of the droplet, rapid vaporization has been observed at the droplet bottom (0ms). The droplet top deforms at 0 ms and then the jet has been ejected from the droplet (0.67 ms). The jet has been separated into small droplets (1-2ms). The maximum height of the

jet reaches up to 100 mm, which is much higher than the initial drop falling height. The droplet jet extraction has not been observed for 30 and 45 mm drop falling height for any surface temperatures. Only for 15 mm drop falling height this phenomena occurs from 240-270^{0}C.

Droplet Jet Extraction Phenomenon:

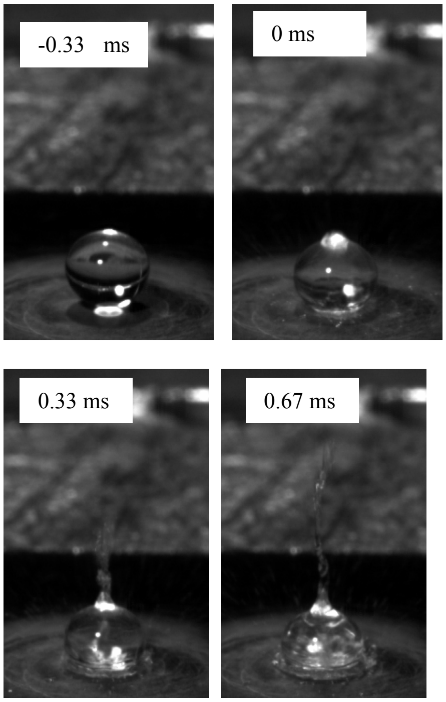

Fig 3: Droplet jet extraction: 15 mm drop falling height (0.54 m/s) and surface temperature 260 ^{o}C.

Fig 4. shows the schematic model of the droplet jet extraction. When the drop impinges the surface, the rapid vaporization causes the high pressure at the droplet bottom. The vapor propagates inside the droplet, and then the jet has been extracted from the top of the droplet.

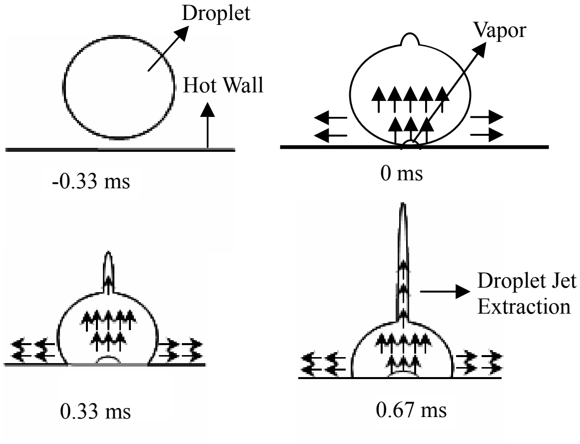

Fig 4: Schematic diagram for droplet jet extraction

Y. Ge et al. (12, 13) discussed the droplet elongation phenomena. It is to be mentioned that temperature of that expt. was film boiling region as a consequence the droplet firstly spreads on the vapor cushion, makes a disk like structure and then the liquid return back from the periphery to the center and make droplet elongation. So in their case elongation phenomena was seen after 20-25 ms. However, in this case droplet jet extraction occurred less than 1 ms and temperature was below Leidenfrost temperature. So this jet extraction phenomenon is different from the Yang's droplet elongation

4. DATA ANALYSIS

With the visualization results, the boiling phenomena has been summarized in Table 2. It is evident that at lower drop velocity, Leidenfrost temperature starts at higher surface temperature and vice versa for higher drop velocity. For higher drop falling height splashing and nucleate boiling occurs at the lower temperature.

Fig. 5 shows droplet lifetime (ms) for different drop velocity and it is vivid that drop velocity affects the droplet lifetime. At higher drop velocity lofetime of droplet increases at lower temperatures as leidenfrost temperature occurs early temperatures.

The drop falling height, i.e., drop velocity influenced the dynamic Leidenfrost temperature a lot and it can be concluded that the the higher the drop velocity, the lower the dynamic Leidenfrost temperature. This same phenomena was analysis by celata et al. [11].

But we have a big Leidenfrost temperature difference with Celata data for 15 mm drop falling height. It is to be mentioned that we cannot measure the specimen temperature directly as the test specimen was on the liquid metal. From this experiment, it is moreover clear that in the regime below the Leidenfrost temperature the interaction between a droplet and a wall depends strongly on the wall temperature and on the impact energy. In the regime above the Leidenfrost temperature the interaction process is governed by the impact energy, whereas the influence of the surface temperature on the interaction phenomena is negligible.

Table 2: Boiling phenomena for different drop velocity versus surface temperatures

Temp (^{0}C)	Boiling Phenomena between hot wall and droplet		
	15 mm drop falling height	30 mm drop falling height	45 mm drop falling height
200	Sp. & N.B	Sp. & N.B	S.D, Sp. & N.B.
220	Sp. & N.B	Sp. & N.B	S.D, L.P & Sp.
240	Sp. & N.B	Sp. & N.B	S.D, L.P & Sp.
260	SD, Sp. & N.B	Sp. & N.B	S.D. & L.P
280	SD, Sp. & N.B	Sp. & N.B	S.D. & L.P
300	SD, Sp. & N.B	L.P	S.D. & L.P
320	DB & Sp.	L.P	-------------
340	DB & Sp.	------	………….
360	L.P	……	-------------

Note:
Sp.- Splashing, N.B- Nucleate Boiling, S.D- Divided into Small Droplets, L.P- Leidenfrost Phenomena
---- Tests were not performed corresponding this temperature

Droplet lifetime on the hot wall changes with surface temperatures as well as drop velocity. For almost all drop velocities droplet lifetime increases abruptly after attaining the Leidenfrost temperature. The reason is that after Leidenfrost phenomena, the heat transfer between droplets and hot walls reduces due to the vapor cushion created between hot walls and droplets as a consequence lifetime of droplets increases more. As a result for lower drop velocity, droplet lifetime increases at higher temperatures and vice versa for higher drop velocity.

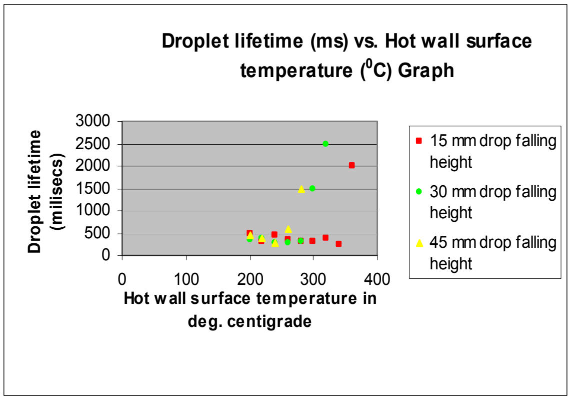

Fig 5: Droplet Lifetime (ms) Vs. Hot Wall Surface Temp. (^{0}C) Graph

5. DISCUSSION

From the analysis it has been observed that surface temperature and surface roughness affects the droplet jet extraction phenomena significantly.

i. Surface Temperature

From the analysis of the extracted pictures it is seen that surface temperature affects the droplet jet extraction phenomena. The phenomenon occurs from 240^{0}C to 270^{0}C.Below 240^{0}C jet extraction phenomenon does not occur as during that time nucleate boiling occurs and at the upper temperature of this range it does not occur because at these temperatures vapor cushion created between the droplet and contact surface which make vapor insulation and prevent rapid heat transfer from hotter surface to the droplet.

ii. Surface Roughness

From the analysis it is also confirmed that surface roughness has an important role in case of droplet jet extraction phenomena. With the new specimen, jet extraction phenomena does not occur at any drop velocities. But the jet extraction phenomena occurred for the specimen which have higher surface roughness. The reason is that with higher surface roughness nucleate site density increases in the surface which accelerate the rapid heat transfer and produces vapor cloud and finally that vapor cloud makes droplet jet extraction phenomena.

The following figure represents surface roughness Vs. Material (SUS304) graph. Graph 1 of Fig 6. represents the surface roughness of the new SUS304 specimen and graph 2 represents the surface roughness of the used SUS304. From the comparison of the graphs it is seen that surface roughness of the used specimen is very high and this higher surface roughness is responsible for jet extraction phenomena.

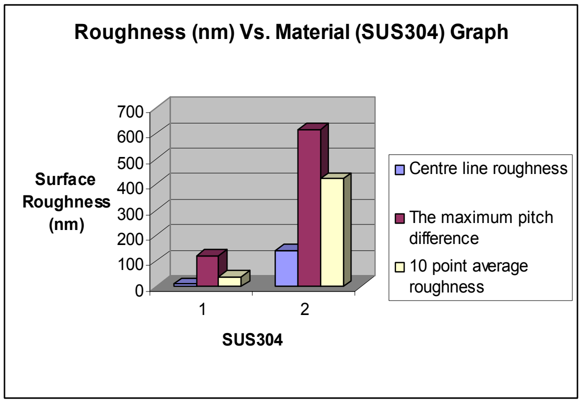

Fig 6: Surface Roughness Vs. Material (SUS304) Graph

6. CONCLUSIONS

The interaction of a drop impinging on a hot wall has been studied visualizing the drop impact with a high-speed video camera at 3,000 frames per second. The effects of the drop velocity (from 0.54 to 0.94 m/s) on the dynamic Leidenfrost temperature, droplet jet extraction and boiling phenomena have been investigated.

The droplet jet extraction phenomenon has been discovered at the certain velocity and temperature. The mechanism of the jet extraction has been qualitatively evaluated. The rapid vaporization causes pressure wave to extract the jet from the top. The phenomenon is considered to be sensitive to the surface roughness, surface temperature and drop velocity and so on.

7. REFERENCES

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8. NOMENCLATURE

Symbol	**Meaning**	**Unit**
T_w	Surface Temperature	^{0}C
D	Drop Diameter	m
ρ	Density of Water	Kg/m^3
u	Drop Velocity	m/s
μ	Dynamic Viscosity	Ns/m^2
Re	Reynolds Number	--------
σ	Surface Tension	N/m
We	Weber Number	--------

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