Proceedings of the
International Conference on Mechanical Engineering 2009
(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

ICME09-TH-17

EXPERIMENTAL INVESTIGATION OF SESSILE DROP EVAPORATION AND ITS RELATION WITH LEIDENFROST TEMPERATURE

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ABSTRACT
This study experimentally investigates the evaporation of sessile drop for four different heated surfaces of Aluminum, Brass, Copper and Mild steel with a combination of four different liquids as Methanol, Ethanol, Water and NaCl solution. The metallic surfaces were polished with a zero grade emery paper and are electrically heated upto temperatures varied from 100 to 400 ^{o}C with an increment of 25 ^{o}C. The time of evaporation for the droplet on the hot metallic surface was measured. According to the experimental data, the Leidentfrost temperature is within a range of 150 to 200 ^{o}C for all the experimental conditions. Sessile drop evaporation time is the maximum for water, then decreases gradually for Nacl solution, Methanol and is the minimum for ethanol for a particular solid material. On the other hand, this time is the highest for copper and the lowest for mild steel for a specific liquid.

Keywords: Evaporation, Sessile Drop, Conduction

1. INTRODUCTION
The Leidenfrost phenomenon is the film boiling of discontinuous liquid masses on a flat surface. The surface temperature corresponding to minimum heat flux is generally termed as Leidenfrost temperature. Many studies of the Leidenfrost phenomenon have appeared in the literature and a brief review of only the most recent must suffice here. Gottfried [1] have presented evaporation time data for small droplet of five ordinary liquids and have proposed an analytical model which is in fair agreement with the data. The model postulates that heat is transferred to the droplet by conduction from the plate below the drop through the supporting vapor film and by radiation from the plate; mass is removed by diffusion from the outer surface and by bulb evaporation from the lower surface; the drop is supported by the excess pressure above atmospheric in the flowing vapor film under the droplet.

Baumeister [2] analyzed the evaporation rate of larger masses, especially those smaller than the critical size for bubble break-through and obtained good agreement between theory and experiment. Patel and Bell [3] obtained evaporation rate data for masses up to 10ml; they also studied bubble dynamics in the 10ml masses photographically and found that the results were consistent with the submerged surface film boiling studies of Hosler and Westwater [4] and with the prediction of Taylor instability theory. In present study, the total evaporation time was determined for small droplets of four different liquids on four different metal plates. The temperature of plate ranges from 100º C to 400º C. The longest time among the times of evaporation of a droplet for a particular liquid, particular solid metal and of different temperatures termed as leidenfrost point was determined from the experimental data. Tamura and Tanasawa [5] studied the total evaporation time of a liquid drop on a hot surface at temperature up to 900ºC. Ten liquids were used including the pure substances ethanol, benzene and water and the mixtures gasoline, kerosene and heavy oil. Their apparatus consisted of a 16cm diameter stainless steel plate with a concave surface. Small droplets were placed on the plate and the evaporation process observed and photographed. Plate temperatures starting about 50ºC below the liquid boiling point and ranging beyond the point where the combustible liquid ignited resulted in evaporation curves that covered all regions of boiling. Since the initial drop sizes in all but one case were smaller than those used in this investigation, it is not possible to compare actual evaporation data, but the general shape of the curves is the same.

The question of the stability of the Leidenfrost phenomenon usually quickly reduces to a discussion of the Leidenfrost point and how it was determined, since the most workers are agreed that film boiling becomes increasingly stable relative to nucleate and mixed modes at increasing surface temperatures. However, very little agreement exists between various workers on the true value of the Leidenfrost point for any given set of conditions.

2. EXPERIMENTAL PROCEDURE

The sessile drop apparatus was used to study the evaporation characteristics of droplet on a heated surface. In particular, the liquid-solid interface temperature corresponding to the Leidenfrost Temperature was determined from droplet evaporation curve for different materials of different liquid.

The experimental setup consists of metal block, one stand, two heater, one variac, one thermocouple and one dropper (as shown in the Fig.1). The working fluids were water, NaCl solution, methanol and ethanol. Two 500 watt cartridge heaters were used to heat the metal block and they were placed beneath the test surface by drilling the block. K type Chromel-Alumel thermocouple was used to determine the center temperature of the testing surface. The thermocouple was installed 3 mm below the test surface.

Regulated electrical energy was supplied to the heater by using a variac, connected to the 220 volt laboratory power. A couple of syringes were used to drop the liquid droplets on the test surface. The syringe was held perpendicular to the horizontal test surface and droplets were released from about two inches from the surface. Though the test surface was little concave, it is assumed that heat is transferred to the droplet from a flat surface.

From the schematic of the experimental apparatus it is seen that heating surface was heated from the bottom by using two cartridge heaters. When the temperature reached a predetermined value (around 100ºC), a droplet was dropped to the center of the heating surface with a syringe; evaporation time was measured using measured using a stopwatch. The droplet temperature was room temperature when dropped.

The surface temperature was measured using a digital multimeter and a 1-mm-diameter chromel-alumel (type K) thermocouple located 2 mm beneath the center of the test surface. Some of the observation of the evaporation activities was captured using a video camera.

The droplet's initial diameter was calculated as a sphere from the measured average volume of 30 droplets. There may be a little error in measuring the diameter of the droplets. A digital stopwatch was used to record the time. To minimize the timer (± 0.01sec) and initial droplet size errors, three evaporation times are recorded for each temperature increment and then average together. This procedure is performed for 25ºC surface temperature increment.

3. RESULTS AND DISCUSSION

The experimental total vaporization time results are shown in Fig. 2 to Fig. 6. The temperature which gives maximum evaporation time is presumed to be the minimum heat flux at which stable film boiling can exist and is termed as Leidenfrost temperature. To the smaller of the Leidenfrost Temperature, the boiling is in transition regime between nucleate and film.

From Fig. 2, it is shown that water stands out compared with the other liquids by virtue of having a much longer vaporization time. The Leidenfrost time for water and NaCl solution are nearly equal. On the other hand both methanol and ethanol shows small value of Leidenfrost time.

Fig. 3 shows that the Leidenfrost time is the maximum for water when the sessile drop is poured on the brass surface. The other three fluids show similar characteristics on brass surface.

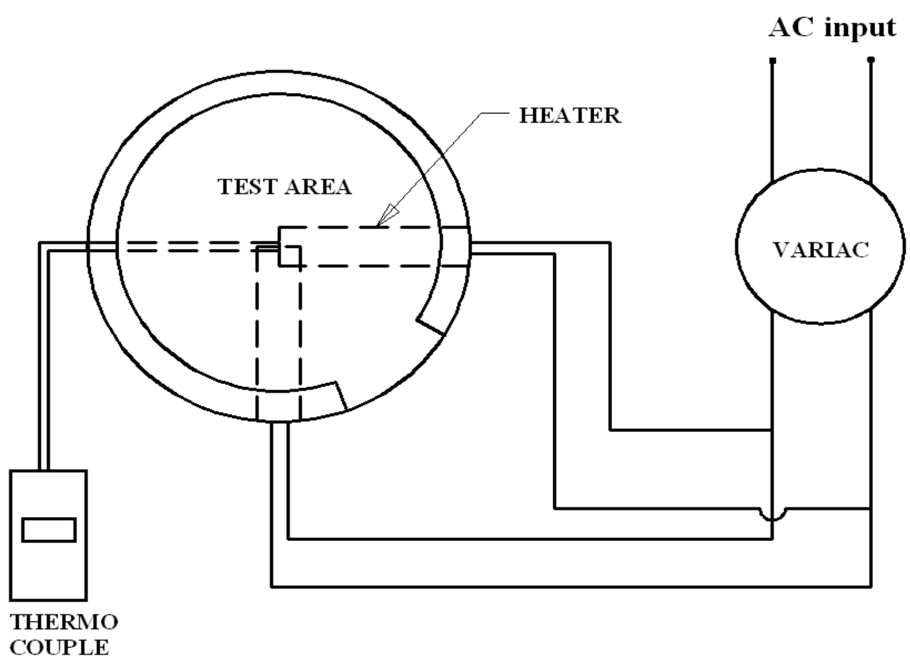

Fig 1. Experimental Setup

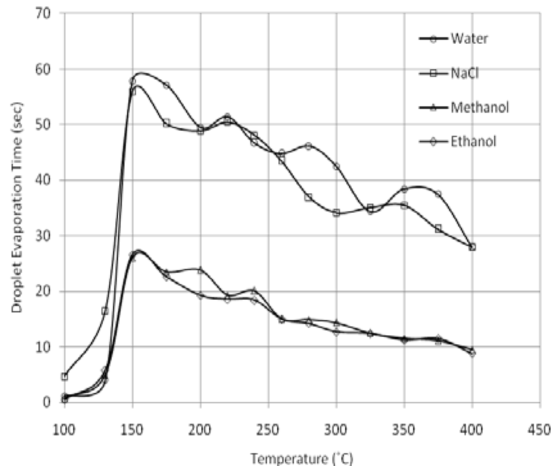

Fig 2. Comparison of Droplet Evaporation Time of Water, NaCl solution, Methanol, Ethanol on Aluminum

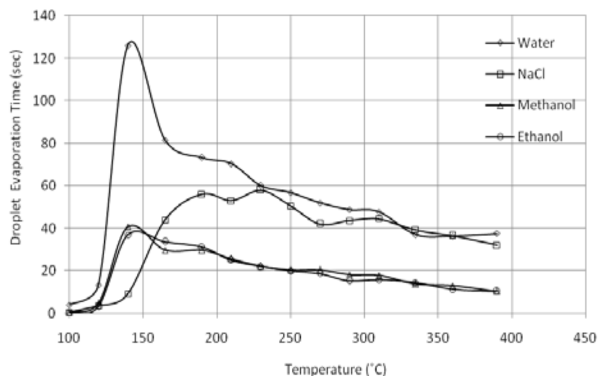

Fig 3. Comparison of Droplet Evaporation Time of Water, NaCl solution, Methanol, Ethanol on Brass

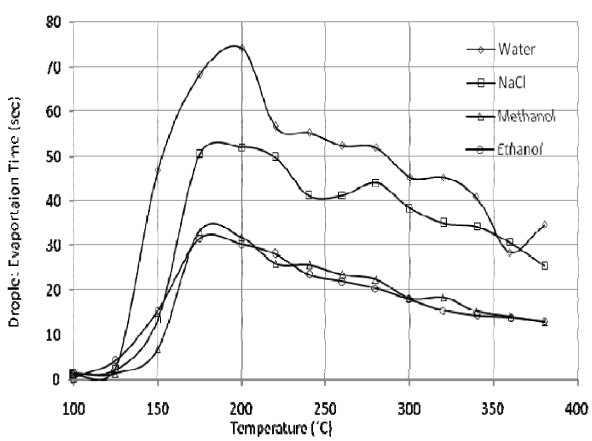

Fig 4. Comparison of Droplet Evaporation Time of Water, NaCl solution, Methanol, Ethanol on Copper

Fig. 4 also shows that the Leidenfrost time is nearly equal for methanol and ethanol. It is also evident from the graph that water shows the highest evaporation time among the four working fluids. Fig. 5 shows the variation of droplet evaporation time on mild steel surface for four different liquids. They show comparable results.

A material of high thermal conductivity would be expected to give a higher and more consistent value of the Leidenfrost time than one of low thermal conductivity. Few exceptional results were also observed due to uncertainty of the experiment. Leidenfrost temperature values were obtained for water, NaCl solution, methanol and ethanol on aluminum, copper, brass and mild steel surface. The Leidenfrost temperature is nearly identical for aluminum, brass and mild steel surfaces but is slightly higher for the copper surface Bernardin [6].

Fig. 6 represents the variation of evaporation time for NaCl solution on four different metallic surfaces. Aluminum, Brass, and Copper shows comparable times but mild steel results in shorter time which may due to lower value of conductivity of mild steel relative to other materials.

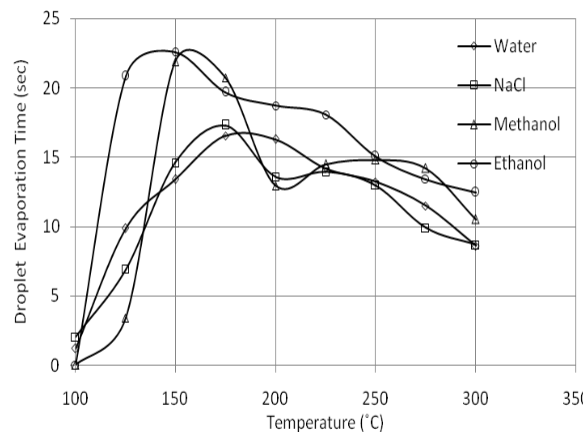

Fig 5. Comparison of Droplet Evaporation Time of Water, NaCl solution, Methanol, Ethanol on Mild Steel

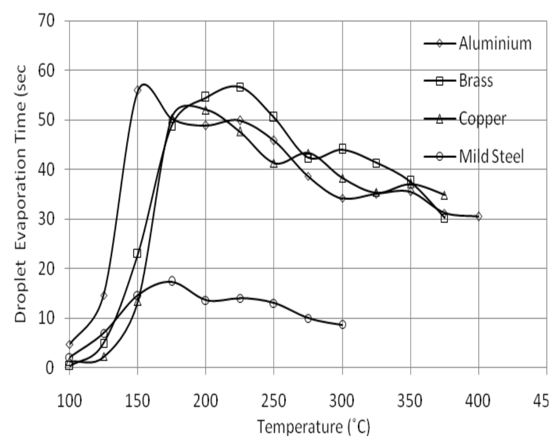

Fig 6. Comparison of Droplet Evaporation Time of NaCl on Mild Steel, Aluminum, Brass, Copper.

Table 1: Experimental Leidenfrost Time

Liquids	Leidenfrost time(sec)			
	Experimental			
	Cu	Al	MS	Brass
Water	74.29	57.79	45.16	126
NaCl solution	51.95	55.89	36.36	56.07
Methanol	33.75	26	21.9	29.65
Ethanol	31.47	26.61	22.58	36.96

Table 2: Experimental Leidenfrost Temperature(C)

Liquids	Leidenfrost temperature(˚C)			
	Experimental			
	Cu	Al	MS	Brass
Water	200	150	250	140
NaCl solution	200	150	275	190
Methanol	175	150	150	165
Ethanol	175	150	150	140

Table 1 and Table 2 shows the experimental Leidenfrost time and temperature of four different liquids on the four different metal surfaces. According to the experimental data, the Leidentfrost temperature is within a range of 150 to 200 ^{o}C for all the experimental conditions (as also shown in the Figs. 2-6).

The higher drop evaporation value of copper surface is speculated to be the result of higher conductivity than other metal. Higher conductivity means higher heat transfer through the metal. It means, when liquid touch the metal, large amount vapor will produce due to higher heat transfer rate and the surface is completely covered by a vapor blanket and then heat transfer from the surface to the liquid occurs by conduction through vapor. Droplet supported by the vapor film slowly boils away.

From the experimental results, several key conclusions concerning the influential parameters (Leidenfrost Temperature) can be drawn. The major contribution to the heat transfer is the convective and conductive mode. The radiative heat flux cannot be neglected at plate temperatures beyond the Leidenfrost point of liquids.

4. CONCLUSION

On a hot surface, a liquid droplet gets heat by conduction from the vicinity of the surface, by convection between the hot surface and the bottom of the liquid surface and by radiation form the hot surface. After getting heat energy, the droplet starts evaporating. At the bottom of the droplet, the vapor forms and leaves just like a vapor explosion. The reaction force of this vapor ejection made floating the tiny liquid droplet which consequences a gap between the hot surface and the droplet. This separation creates a heat resistance and then naturally the heat transfer between the solid and the liquid reduces which ultimately reduces the rate of vapor generation. This vapor is not capable to maintain the gap and at last the liquid droplet again falls down to the solid surface and the cycle starts again. This cycle repeats until the volume of the droplet tends to zero.

Sessile drop evaporation time is the maximum for water, then decreases gradually for Nacl solution, Methanol and is the minimum for ethanol for a particular solid material. On the other hand, this time is the highest for copper and the lowest for mild steel for a specific liquid. The radiative heat flux dominates the heat transfer process beyond the Leidenfrost temperature.

5. REFERENCES

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