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Experimental Investigation of the Variation of Droplet Evaporation Time and Leidenforst Point with Different Impact Heights at Different Temperatures

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Abstract

This study experimentally investigates how evaporation time for droplets of three different liquids (water, ethanol, methanol) and their corresponding Leidenforst point (LFP) change with the impact height of droplet. In the experiment, aluminum surfaces polished with emery paper (1200 grade and 1600 grade) were electrically heated up to temperatures varied from 100 to 400℃ with an increment of 10℃ and the height of droplet was changed from 1 to 10 cm with an increment of 1cm. The time of evaporation for the droplets on the hot metallic surface was measured by a stopwatch. The experimental data suggest that (a) above certain temperature range (around 160℃) droplet evaporation time decreases with the increase of impact height and (b) variation of LFP point with respect to impact height is insignificant.

Keywords: Evaporation, Leidenforst Point, Impact Height.

1. Introduction

Droplet evaporation time is one of the crucial parameters of the droplet evaporation phenomenon which is being extensively used in the heat exchanger operations and metallurgical, nuclear and electronic industries nowadays. And this type of evaporation possesses a slightly different mechanism than two very basic kinds of boiling: pool boiling and flow boiling. Various sorts of factors such as the size of droplets, materials and roughness of the surface, impact height, contact angle, hydrophobicity and so on affect this phenomenon. A plethora of studies on this phenomenon, concerning these various factors, have appeared in the literature and a brief review of only the most recent must suffice here. Gottfried et al. [1] proposed an analytical model by analyzing evaporation time data for the small droplet of five ordinary liquids and that model was in fair agreement with the data. The model postulates that heat is transferred to the droplet by conduction from the plate below the droplet through the supporting vapor film and by radiation from the plate; mass is removed by diffusion from the outer surface and by evaporation from the lower surface. Bonacina et al. [2] investigated the heat transfer characteristics of dropwise evaporation of relatively low values of excess temperatures and postulated a simplified dimensionless form which correlated the fraction of the total heat transfer area covered by droplets to the dimensionless values of heat transfer coefficient. The equation was verified with the results of optical observations and thermal measurements and the agreement between the theory and experiments was impressive. Ruiz et al. [3] conducted a numerical analysis of the evaporation process of small water droplets with diameters of 1 mm or less. The numerical simulation has demonstrated that the internal fluid motion, occurring as a result of thermocapillary convection, provides vastly different temperature distribution in the drop compared to the results from the heat conduction model that neglects fluid motion. Chandra et al. [4] studied the effect of varying initial liquid-solid contact angle on the evaporation of single droplets of water deposited on a stainless steel surface. They suggest that reducing the contact angle increases the contact area between the droplet and solid surface, and also reduces droplet thickness, enhancing heat conduction through the droplet. Both effects increase the droplet evaporation rate. Decreasing the initial contact angle from 900 to 20° reduces droplet evaporation time by approximately 50%. Nguyen et al. [5] investigated the effect of substrate hydrophobicity on the lifetimes of evaporating droplets for both the droplets with a constant base radius (pinning mode) and a constant contact angle (depinning mode). They identify that linear methods of extrapolating limited experimental data for a transient droplet contact angle and base radius overpredict the droplet lifetime. Thus, they suggest a new model which removes inconsistencies in the previous theory and experimental analysis and proposes master equations and master curves for the droplet lifetime for the two evaporation modes and they are validated by the experimental data. These equations and curves insinuate that droplets on a moderately hydrophobic surface evaporate more slowly than on a hydrophilic surface, except on a superhydrophobic surface (where the contact angle is larger than about 150°). On the other hand, Leidenforst point is defined as the surface temperature corresponding to minimum heat flux and this point is presumed as the temperature which gives the maximum evaporation time. Bernardin et al. [6] present a detailed and thorough parametric study of the Leidenfrost point (LFP). With the help of accumulated LFP data of that study, they find out the disagreement between the experimental LFP values and those predicted by the various models and thus suggest that an accurate and robust theoretical model which effectively captures the LFP mechanisms is currently unavailable. In this current study, we only concentrate on and experimentally investigate whether evaporation time for droplets of three different liquids (water, ethanol, methanol) and their corresponding LFP points change with the impact height of droplet.

2. Experimental procedure

The experimental setup was predominantly a 3.5-inch diameter and 3-inch height aluminum block. A thermocouple was installed 2 mm below the test surface. The test surface of the blocks is polished by emery paper (1200 grade and 1600 grade). From the schematic of the experimental setup, it is perceived that the aluminum surface was heated by heater inserted into the block. When the surface temperature has reached a value of 100℃, a drop of the working liquid is made to fall on to the surface from a height of 10cm and the boiling time of that drop is measured using a stopwatch.

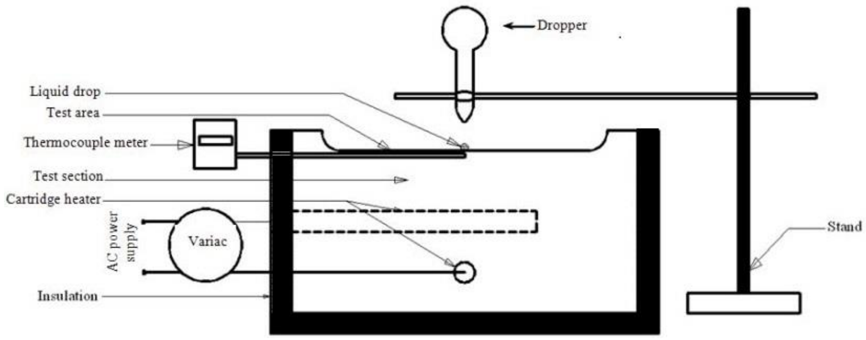

Fig. 1. Experimental setup

The temperature was maintained at a constant value by controlling the voltage by VARIAC and in the same way evaporation time data for other 9 heights (9cm, 8cm and so on up to 1cm) were measured. Then again using the VARIAC, the temperature of the test surface was raised to 110°C and this procedure was repeated. The whole procedure was repeated for other liquids up to 400°C with a step increase in temperature of 10°C. All the readings were taken at a constant temperature point and it took different times to fix the temperature. Thus, temperature increment time wasn't an experimental consideration here. The volume of each drop was calculated by taking the average of 30 droplets. The volume was found to be somewhat 2.78mL. It is to be noted that this value is just an approximation, thus some errors might be associated with it.

3. Result and discussion

The experimental total evaporation time data are shown in Fig. 2 to Fig. 4. It is noticeable from the Fig.2 that the variation of evaporation time of liquid droplets with the impact heights of (1-10) cm occurred within a very small range at relatively low temperatures. For example, at 120°C, the evaporation time ranges from 2.71 sec to around 2.1 sec for water, 1.56 sec to 0.62 sec for ethanol and 2.8 sec to 4.49 sec for methanol. The variation was very irregular and we couldn't quite get much of a trend for the variation with heights. It occurs because from the boiling curve it is evident that the heat flux is very high at these low temperatures. So, the evaporation time, at these relatively low temperatures, is very little and is difficult to measure this little time precisely. This irregular trend occurred up to 160℃ for water, 130℃ for ethanol and 160℃ for methanol. It is conspicuous from Fig. 3 and Fig. 4 that evaporation time decreases gradually with a gradual increment of heights and this trend is almost similar for all the temperatures up to 400℃ for all the three liquids we tested. This phenomenon is obvious because drops falling from higher heights will exert the higher force on the surface during impact and hence scattering and breaking of droplets will occur. This means a single droplet will become multiple droplets after impact. This will increase the surface area thus the higher heat transfer resulting in less time requirement in evaporation for higher impact heights. Besides, some small portion of the droplets may fall out from the test surface resulting in the reduction of the actual droplet volume. Nevertheless, we couldn't prohibit this error, reduction in evaporation time with higher impact heights is evident from the following graphs of Fig. 3. and Fig. 4. The experimental data plotted in these two graphs show a trend, but some data points fell out of the trend.

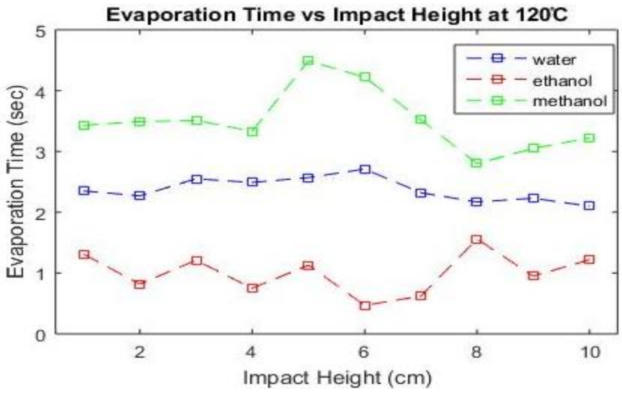

Fig. 2. Evaporation time vs height at 120˚C

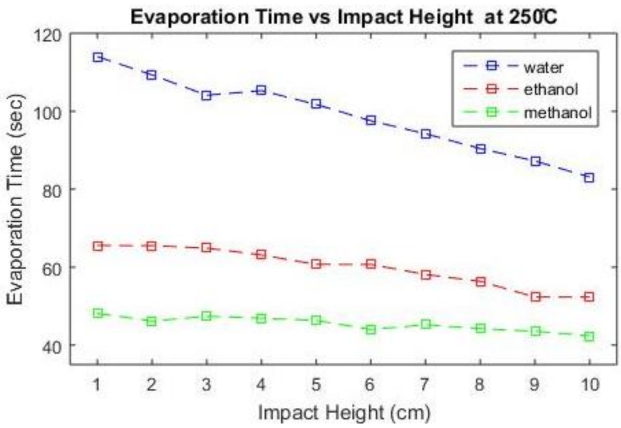

Fig. 3. Evaporation time vs height at 250˚C

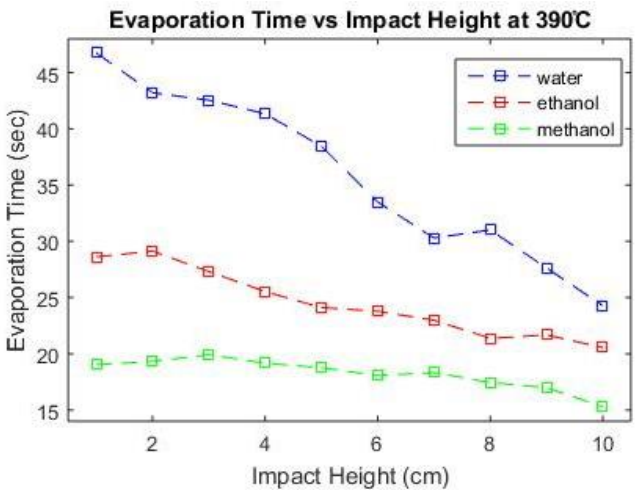

Fig. 4. Evaporation time vs height at 390℃

This is because of some experimental errors such that the slight irregularities in droplet volumes and the rapidly fluctuating temperatures and hence it was very much difficult to take the evaporation time readings at a certain constant temperature.

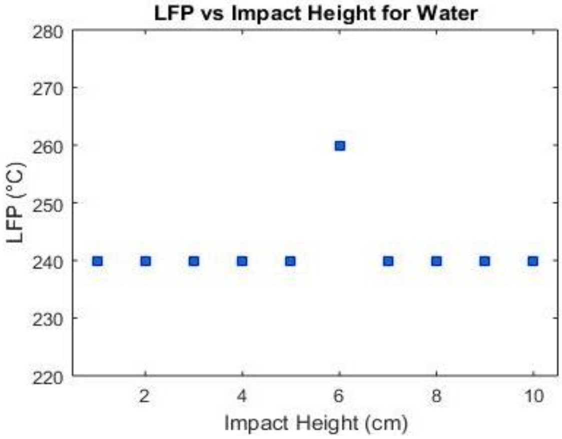

Fig. 5. LFP vs height for water

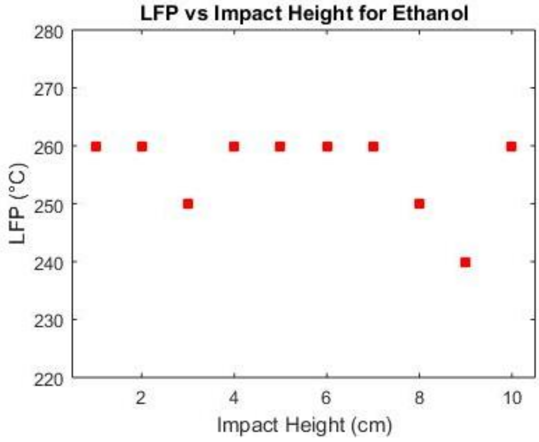

Fig. 6. LFP vs height for ethanol

In addition, the most prominent errors might have resulted from the varying roughness of the test surface. However, the variation of roughness was out of the scope of this experiment, therefore the roughness effect on evaporation time was neglected. At this point, the variation of LFP point with impact height is presented in Fig. 5 to Fig. 7. In these graphs, no regular trend is found concerning the variation of LFP point with impact height. The temperature at which the Leidenforst effect begins to occur is very difficult to predict. Even if the volume of the droplet of liquid stays the same, the LFP point may be quite different, with a complicated dependence on the properties of the impact surface as well as impurities in the liquid.

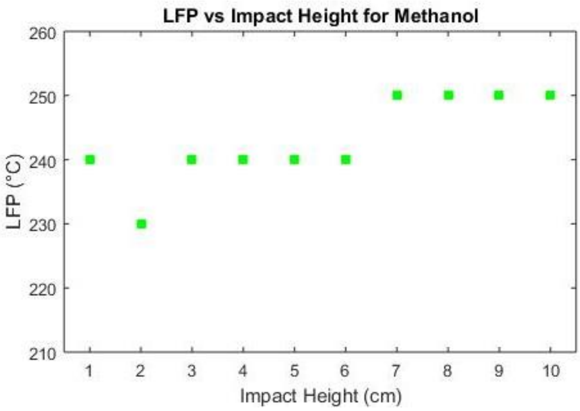

Fig. 7. LFP vs height for methanol

Some research has been conducted into a theoretical model of this phenomenon, but it is quite complicated. However, LFP points were measured against the points at which heat flux was minimum and evaporation time was maximum. The range of LFP points is 230℃ to 240℃ for water, 240℃ to 260℃ for ethanol and 240℃ to 250℃ for methanol and these are validated by the data found in Mozumder et al. [7].

4. Conclusion

From the above experiment, it has been manifested that with an increase of impact height droplet evaporation time decreases above a certain temperature range and in this context the temperature range is up to 160℃ approximately for water, ethanol and methanol. It is also observed that above a certain height droplet evaporation time decreases more rapidly. This critical height is between 4-6cm for these three liquids. However, there is no significant variation of Leidenfrost point with respect to droplet impact height.

5. References

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