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Evaporation of droplet with and without laser excitation

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ABSTRACT

The evaporation of water and ethanol droplets is investigated experimentally. The evaporation rate of the hanging droplets on a thermocouple with and without laser excitation is demonstrated in the study. In the absence of laser excitation, the ethanol droplets are subjected to have a fast evaporation than the water droplets under the open environmental conditions. As the droplets are then exposed to the pulsed laser excitation at different power rating under the frequency of 1 Hz, 3 Hz or 5 Hz. The present of laser excitation leads to a significant temperature increase in the droplets. The evaporation rates are higher than those without laser excitation. It is observed that as the laser frequency and intensity increases, the rate of evaporation and temperature increases generally. The explosive vaporization happens at a higher power at a higher laser frequency for both water and ethanol droplets. However, this phenomenon is much more significant for water as compared to ethanol. The evaporation rate tendency is opposite to the experiments carried out without laser excitation.

1. Introduction

Droplet evaporation is one of the common phenomena in nature and engineering industry. The evaporation can be influenced by the hydrodynamics, temperature variation, interfacial convection, substrate, etc. [1–7]. Explosive boiling or vaporization is a phenomenon happening in chemical, nuclear, or other traditional industries, and other various advanced military or defense technologies, such as laser generated high-power cooling, ink-jetting, spray generation, and so on. To generate the explosive vaporization, one of the heating methods is the use of micro-heaters. Micro-film heaters or thin wires with a pulsed high heat flux have been applied to induce explosive boiling in the liquid phase. The local micro-bubble nucleation and bubble growth were investigated by Skripov et al. [8] and Derewnicki [9], Okuyama and Iida [10], and Glod et al. [11] by using platinum wires. It is found that the bubble nucleation temperatures can be predicted by the homogeneous nucleation theory. It is also found that homogeneous nucleation in the liquid results in the explosive boiling although the relation with the vaporization has not been elucidated. The micro-film heaters were used by Asai [12] and Iida et al. [13] for the studies of the explosive boiling of three different liquid including methanol with a recording of the bubble nucleation and growth with a CCD camera at an atmospheric conditions. They found that the nucleation temperature was a function of the heating rate. The other heating source is laser beams. But, there are limited reports on the heating method. Duffey et al. [14] reported to use a pulsed laser beam on the metallic film for explosive boiling. Leung et al. [15] studied explosive vaporization of a thin liquid film on an opaque solid surface. The problem associated with the experiments using nanosecond pulsed laser to induce the explosive boiling cannot have the quick temperature measurements. An experimental and measurement system of rapid transient explosive boiling was studied in the thin film for acetone liquid with the phenomena of vapor bubble formation and movement were investigated [16]. The droplet experiments in the laser was investigated under the carbon dioxide (CO_2) lasers and the Nd-doped yttrium–aluminum–garnet (Nd:YAG) lasers. Interesting features were observed, such as inhomogeneity generating droplet explosion patterns, delaying in the superheating explosions, evaporative instability, etc. [17]. Since the complex process is in a quite short period, there are still many problems remaining experimental observation. The phenomena of explosive vaporization transition of liquid droplets under laser excitation are far from fully understood. The vaporization rate cannot be expressed. The paper is to focus on the detailed experimental investigation without or with difference laser excitation on the evaporation rate and temperature rise.

2. Experimental

As illustrated in Fig. 1, the droplet at around 1 mm, supplied by a syringe mounted on a syringe pump, was formed on a calibrated K-type and 25 micron thermocouple with an accuracy of 0.5 °C. The experiments of evaporating droplets were conducted in the open conditions at room temperature, 1 atm and about 60% relative

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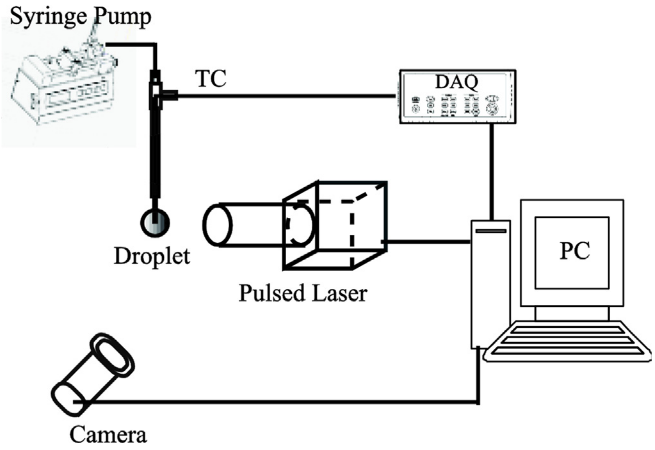

Fig. 1. Schematics of the experimental setup.

humidity. In the experiments, a pulsed laser beam from Liton Laser Nano L120-20 was generated and emitted on the center of droplets through a lens with a frequency of 1 Hz, 3 Hz or 5 Hz as the laser was set at 10%, 20%, 30%, 40%, 50% and 60% of the rated power. A microscopic camera with 30 fps or a high speed camera was used to record the droplet shape continually. At the same time, the temperature in the droplet (TC in Fig. 1) was recorded by a computer via the NI DAQ system. The experimental fluids are deioned water and ACS Reagent Grade ethanol from MP Biomedicals Singapore. The recorded images and temperature were used for the further analysis.

As seen in following figures, as the droplet diameter was controlled at around 1 mm for water and ethanol, the sideview of the hanging droplet approached spherical. The image software, ImageJ, could give us the area, A, then we can estimate the volume, V, with

$$V_i = 4/3\pi^{-1/2}A^{3/2} \tag{1}$$

where the sub i is the instantaneous time, thus the evaporation rate, J, of liquid droplet in the time period from $t1$ to $t2$ can be expressed as

$$J = \rho(V_{t2} - V_{t1})/(t2 - t1) \tag{2}$$

in which ρ is the liquid density, in the experiments, the water density is assumed with a value of 1000 kg/m^3, while the density of ethanol is 789 kg/m^3. If the time period can be exactly recorded

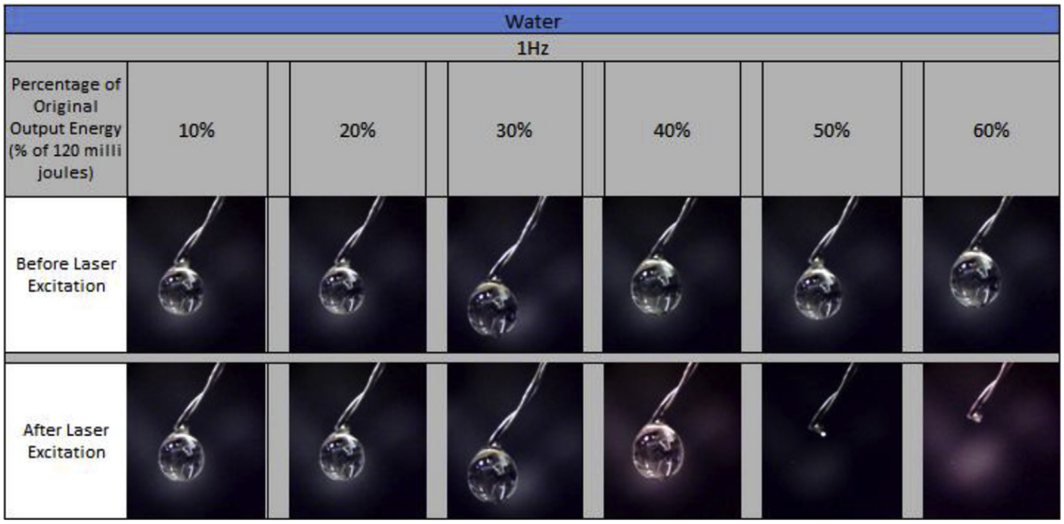

Fig. 2. Water droplets before and after laser excitation at 1 Hz.

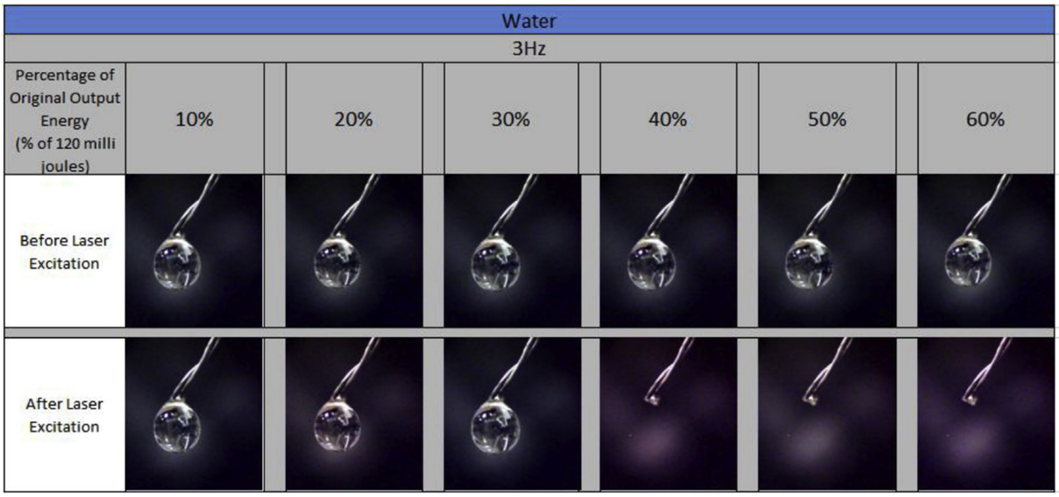

Fig. 3. Water droplets before and after laser excitation at 3 Hz.