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Experimental study of a droplet impacting on a burning fuel liquid surface

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ABSTRACT

A series of experiments were performed to study a single droplet impingement on a burning fuel liquid surface with varying impact velocity. The impact droplet diameter used in this experiment was around 2.2 mm. The impacted liquid was alcohol with the burning surface. The impact process was recorded using a high-speed digital camera at 2000 frames/s. The results show that three typical impact regimes appear, including splashing-injecting, splashing-injecting-secondary injecting and splashing-bubble, which are determined by the impact velocity. The maximum crater depth, width and the maximum jet height have a slight increase when the impact velocity ranges from 2.351 m/s to 3.357 m/s, but the maximum heights of the crown are almost constant. As the impact velocity is continuously increased to 3.513 m/s, the maximum crater depth, width and the maximum crown height have a sharp decline. In addition, fire plume has evident influence on the loss rate of the impact velocity.

1. Introduction

Liquid droplet impact on a solid or liquid surface has been focused for extensive practical applications [1–14], such as spray cooling, dissolved oxygen increment, inkjet printing [15], thermal spray coating by depositing molten onto a substrate, atmospheric science, and fire suppression by spray/water mist [16]. So understanding of the drop/surface interaction is very important in these applications.

From a scientific standpoint, the droplet impingement on liquid surface involves some typical phenomena such as bouncing, coalescence, injecting and splashing [1,17–19], which are determined by the liquid viscosity [20], the impacted liquid depth, the droplet impact velocity [21], physical properties of liquid and droplet, and the added surfactant [17]. Although there is a lot of literature about a droplet impinging on liquid surface, the interaction of droplet with a burning surface is hardly touched from the perspective of fire suppression.

In order to study fire suppression, Manzello and Yang [22] employed the hot plate to heat the liquid to mimic a burning liquid surface and observed the droplet impingement. They found that the critical impact Weber number for splashing is dependent on liquid pool temperature, and decreases with an increase of liquid temperature. Wang [16] experimentally studied the suppression mechanism by water mists. They used three kinds of fuel, i.e. alcohol, kerosene and diesel, which were separately heated by water bath. It was found that the drop Weber number and liquid temperature have effects on the diameter size of the splashed drop and bounced jet height.

Generally, the above modeled liquid surface is not a real one with burning surface, which possibly leads to significantly different stress inside the liquid or fuel. Moreover, the effect of fire plume on the droplet impact velocity is not taken into account. Especially, the micro impact process is also unclear when the droplet impacts on the burning liquid surface. So, in order to address these, in this paper, a series of experiments on water droplet impacting on a burning fuel liquid surface was carried out.

2. Experimental setup

Fig. 1 presents the schematic diagram of experimental setup. The droplet is generated at the tip of the injection syringe and falls down under its own force of gravity. The water which used in this experiment is highly purified and the temperature of the impact drop is fixed at 25 °C. To get different impact velocity, the distance *H* between the burning surface and the tip of the needle is set as 38.6 cm (case 1), 45.9 cm (case 2), 62.5 cm (case 3), 81.6 cm (case 4), 92.2 cm (case 5) and 103.3 cm (case 6) and 127.6 cm (case 7),

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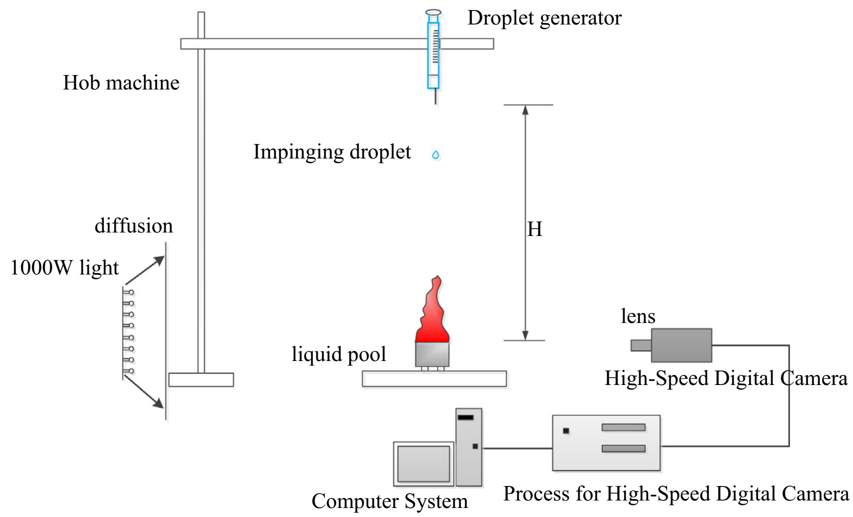

Fig. 1. Schematic diagram of experimental setup.

respectively. It should be noted that at least 10 tests were performed for each distance. Alcohol is chose as target fuel liquid and the liquid container is made of transparent quartz glass with the size of 75 mm (length) × 75 mm (width) × 80 mm (height). Since the drop size in all experiments is fixed at about 2.2 mm and moreover the distance between the pool wall and center is 30 times larger than the radius of the drop, the wall effect can be ignored in this study [23]. The fuel in the pool is alcohol and its flame configuration is demonstrated in Fig. 2.

Droplet impingement was recorded using Phantom V710 Digital High-Speed Camera with a Nikon 60-mm micro lens. A 1000 W Iodine–Tungsten light was used as a strong illuminant together with a thin sheet paper as a diffuser. Similar to previous studies [17,24], the mean drop diameter is determined by image and can be expressed as

$$D_m = \left(D_x^2 D_y\right)^{1/3} \tag{1}$$

where D_x and D_y are the drop diameter in the x and y directions, respectively.

3. Results and discussion

3.1. Impact behavior

In current study, the impact Weber number is used to analyze the impact behavior. It is defined as $We = \rho V_2^2 D_m/\sigma$, where D_m, ρ, V_2 and σ are the droplet diameter, density, experimental value of the impact velocity and the droplet surface tension, respectively. It should be noted that only the impact velocity was a variable in this correlation. Physical properties of the water drop are listed in Table. 1.

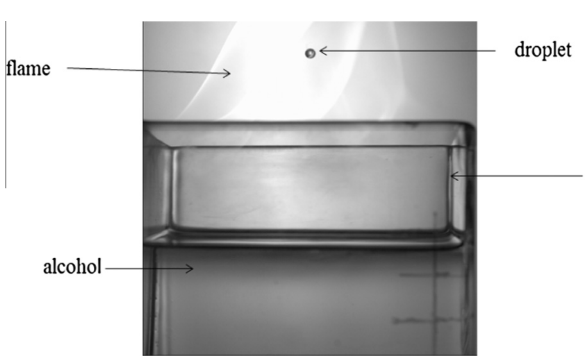

Fig. 2. The falling droplet and flame on the burning fuel.

Although previous research [16] reported that the influence of the drop Weber number and target liquid temperature on impact behavior was not evident compared to the type of liquid fuel, the impact behavior was obviously affected by the Weber number in current study. With the increase of Weber number, three different regimes of the drop impact on alcohol were observed for cases 1–7 and three typical phenomena are shown in Figs. 3–5 respectively.

3.1.1. Splashing-injecting regime

For H = 38.6 cm (case 1) and H = 45.9 cm (case 2), the impact behavior shows the similar regime. Fig. 3 shows the time-elapsed images of a water droplet impinge on the burning alcohol surface for H = 45.9 cm (W_e = 190). The time when the droplet touched the target surface was set as 0 ms. At 3 ms after the impact, a crater could be easily observed and the edge of crater expanded outward slowly, as shown in Fig. 3(b). A structure like crown formed and gradually became larger and larger at the impact point. Some small droplets with the size of about several hundred microns, which were generated from the upper rim of the crown wall, were injected from the wall. At 8 ms, the crown wall reached the highest position, and then began to collapse. The crater continued to expand outward until the crater depth approached the maximum value at 15 ms. Then, all round fluids began to flow inward to fill the crater and the apex points of the crater began to move upward at 40 ms. A jet column crossed the free surface and rose up continuously until the upward velocity decreased to zero. Then the jet began to break up and formed a single large droplet. At 145 ms, the impacted process finished, but the water wave train continued spreading on the fuel surface.

The phenomena appearing in cases 1 and 2 have some obvious difference with the previous study in which impacted liquid is unburned. Firstly, Liow [25] conducted similar experiments with similar droplet size as those in our test and reported that the crown cannot form when Weber number is less than 395 for a droplet

Table 1
Thermophysical properties of the water drop.

Fluid	Density (kg/m^3)	Surface tension (N/m)
H_2O at 25 °C	996.9	0.072