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Phase-Separation Inside a Burning Droplet of Oil-in-Water Emulsion

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Abstract : An experimental study was performed to obtain the detailed information needed for the deep understanding of the combustion process and the secondary-atomization of an oil-in-water emulsion droplet. The experiments were conducted by using the drop shaft of JAMIC (Japan Microgravity Center) at Hokkaido. The oil-in-water emulsion which consisted of n-hexadecane as a base fuel, distilled water and a trace of surfactant was tested. Photographic observation and temperature measurement were made of the suspended emulsion droplet during the heating-up and combustion processes under microgravity. The results showed that the separation of the base fuel and water as well as their agglomeration and coalescence occurred with the lapse of time. The increase in the droplet temperature resulted in the phase-separation, the formation of a single water droplet enveloped by a shell of the base fuel, prior to the microexplosion. The volumes of the base fuel and the water in the droplet were estimated from the obtained droplet images. After the phase-separation, selective evaporation of the base fuel would occur, and the volume of the base fuel decreased while the water volume did not change. The effects of the emulsion properties on the onset rate of microexplosion were also revealed by using statistical analysis.

Key words : Combustion, Emulsified fuel, Microexplosion, Droplet combustion, Microgravity, Water content

1. Introduction

Emulsified fuel combustion method has been recognized to cause the improvement of the combustion efficiency and the reduction of pollutant emissions including unburned hydrocarbons, nitric oxides and soot. This has resulted in the increased interest in the study on the combustion of emulsified fuels, especially on the microexplosion (secondary-atomization) phenomena of emulsified fuel (emulsion) droplets, such as breaking up of droplets into smaller secondary-droplets, so-called "disruption" (Fig. 1), and blowing-out of vapors laden with fine droplets, so-called "puffing". Evaporation and combustion of a single emulsion droplet have been examined experimentally with free droplets and fiber-suspended droplets or theoretically [1-3]. In most of these studies, the occurrence of the microexplosion has been discussed using the relationship between droplet temperature and the superheat limit based on the homogeneous nucleation theory; The microexplosion would occur in the case that the superheat limit of water is less than the boiling temperature of the base fuel. However, microexplosion or bubble nucleation has been observed at temperatures below the superheat limit for emulsion droplets suspended in heated glycerin [1] and evaporating on a hot surface [2].

The aspects of microexplosion have been found to also depend on the type of the emulsion, or on the properties of the surfactant as mentioned in the previous work [1-4]. The droplet is disrupted after puffing occurs several times for oil-in-water emulsions. The initially opaque and milky-white droplet changes to the transparent one which contains a milky-white droplet inside it before disruption, that is, phase-separation occurs in the droplet.

2. Experimental Procedure

Most of the experiments were conducted by using the

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drop shaft of JAMIC (Japan Microgravity Center) at Hokkaido, which provided 10 s of the effective time of microgravity experiments with high quality. Figure 2 shows the schematic diagram of the experimental apparatus. The experimental apparatus was integrated in the rack for the drop shaft. The combustion chamber was an acrylic-resin box, which was equipped with two windows for the observation of the droplet and for detecting droplet ignition. The well-known suspended droplet technique is adopted; An emulsion droplet was suspended at the spherical tip of a quartz fiber of the diameter 250 mm. A remote-controlled fuel supply system was provided to suspend the droplet right before the microgravity experiment.

3. Results and Discussion

3.1. Water-Coalescence inside Droplet

The initial water content c_w is 0.1. The droplet is opaque and uniformly milky-white before droplet-heating. As shown in Fig. 1, transparent region appears at the side surface of the droplet and the phase-separation starts after heating starts. The progress of the phase-separation results in the formation of an opaque and milky-white region at the center of the droplet. Figure 2 corresponds to the last stage of the phase-separation. The milky-white region is spheroidal and enveloped by a transparent layer; An internal milky-white droplet is formed inside the primary droplet at its center.

3.2. Onset Rate of Disruptive Microexplosion

Experimentally obtained data of the waiting time for onset of disruptive microexplosion of emulsions, which is defined as the time interval between start of heating or ignition and instant of disruptive microexplosion, scatters largely. In the practical point of view, therefore, the onset rate should be introduced to discuss the disruptive microexplosion by assuming its occurrence to be a random process.

The initial water content c_w was varied from 0.1 to 0.4. More than 50 capillaries were used for each experimental condition. The onset rate of explosive evaporation was statistically determined by using the Weibull distribution [5]. The onset rate is defined as

$$J = f(t)/[1-F(t)], \qquad (1)$$

where F is the distribution function and f is the probability density function. The latter is defined as $f(t) = (dF(t)/dt)$. t is the elapsed time from the instant when the emulsion is heated up to the oil bath temperature.

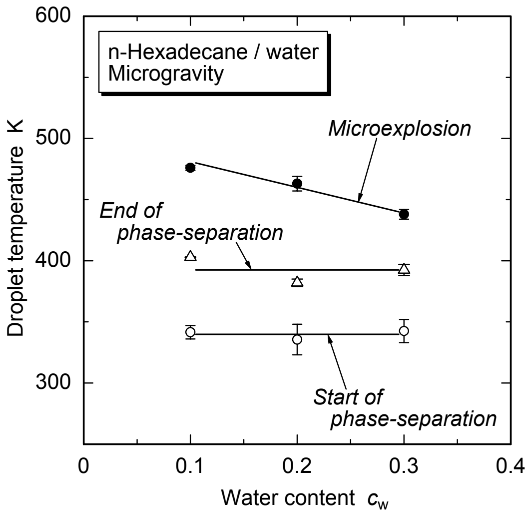

Fig.1 Droplet temperature at start and end of phase-separation and at microexplosion.

4. Conclusions

An experimental study was performed to obtain the detailed information needed for the deep understanding of the combustion process and the secondary-atomization of an oil-in-water emulsion droplet. The experiments were conducted by using the drop shaft of JAMIC (Japan Microgravity Center) at Hokkaido. The oil-in-water emulsion which consisted of n-hexadecane as a base fuel, distilled water and a trace of surfactant was tested.

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