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Relationships between dynamic behavior and properties of a single droplet of water-emulsified n-dodecane

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ABSTRACT

Water-fuel emulsion liquids are used in variety of combustion systems to suppress pollutant emission and to control flame characteristics. However, the characteristics of fluid-dynamics, phase change, and combustion were significantly affected by the variation of the emulsion properties. In this study, three representative properties (i.e., surface tension, dynamic viscosity, and light absorbance) were investigated for water-emulsified n-dodecane as a diesel fuel surrogate. First, these properties were preliminarily measured with three independent ordinary methods, and the property variation coupled with the micro-structures within the emulsion was discussed. After that, a new method able to estimate the same three properties was suggested. An emulsion droplet was disturbed using a pulse-laser, and its dynamic behavior was analyzed based on the Taylor's analogy breakup model. Thus, more reliable properties could be proposed for determining the dynamic behaviors of an emulsion droplet, and the relationship between the properties and dynamic behaviors could be better understood.

1. Introduction

Recently, various water-fuel emulsion liquids have been used extensively in many combustion systems for various purposes. In particular, pollutant emissions including NOx could be suppressed [1–5], and flame stability and combustion characteristics could be controlled [6–8], by varying the composition of water and oil in the emulsion. In addition, the water-fuel emulsion could induce a micro-explosion phenomenon that helped the penetration and atomization characteristics of the fuel [9–12] simultaneously. To understand these phenomena of water-fuel emulsions, preliminary investigations on the significant variation of the emulsion properties were necessary.

Usually, the phases of water-oil emulsions have been classified into two types. One is oil-in-water (O/W) in which dispersed micro-scale oil drops exist within a continuous water pool. The other is water-in-oil (W/O), which has micro-scale water drops dispersed within a continuous oil pool. Such different phases affect the overall properties of emulsions. These emulsion properties will determine the dynamic behaviors of emulsion liquids at the initial stage, and the characteristics of consecutive combustion phenomena will be affected significantly.

Related to the analysis of such phenomena, the most important properties are density, thermal capacity, surface tension, dynamic viscosity, and light absorbance. The density and thermal capacity can be determined by taking a weighted average of the respective properties. However, the other properties such as surface tension, dynamic viscosity, and light absorbance need to be measured in each case. Fundamental trends of the emulsion viscosity have been reported [13,14], and phase inversion and friction have been studied [15]. Light absorbance or turbidity has also been measured [16,17]. One theory often adopted in relation to the droplet deformation is Taylor's analogy breakup model (TAB model) [18], and a modification of this model has been suggested [19]. In such studies, dynamic oscillation and deformation of a single droplet were described with analogy to a simple mass-damper-spring system or a combination of them. However, the relationship between the droplet behavior and the properties has not been clarified specifically for a water-fuel emulsion. Thus, the prediction of the deformation or breakup of the water-fuel emulsion was difficult but very necessary for this analysis.

Many previous studies on droplet behavior have been conducted for pure liquids that were mostly disturbed by external hydrodynamic forces. In contrast, water-fuel emulsions have non-Newtonian characteristics [20], and their unique breakup phenomena (such as the micro-explosions) are strongly concerned with energy transfer. With the purpose to achieve fast energy transfer, in a recent study [21], a pulse laser was used to investigate the free surface dynamics of a pure water droplet on a glass surface. In a more recent study [22], a pulse laser was used to irradiate a free-falling, dyed water droplet, and the disruption process was investigated. Nevertheless, the relationship between the

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Nomenclature

a	empirical constant
C_d	damping coefficient
C_k	spring coefficient
C_F	external force coefficient
d	diameter of droplet
D	outer diameter of tube
E	laser energy
E_{on}	onset laser energy
g	gravitational acceleration
I	light intensity
I_{scat}	light scattering intensity
I_{trans}	light transmitting intensity
$\dot{n}$	rotational speed
O/W	oil-in-water emulsion
R_{vis}	radius of viscometer cylinder
r	radius of droplet
r_0	average radius of droplet
Δr	displacement at a peak
s_{drop}	nominal strain rate of droplet
s_{shear}	average shear strain rate
t	time
t_c	critical time
t_d	damping characteristic time
u	relative velocity
W/O	water-in-oil emulsion
X	volumetric fraction
x	length
y	normalized displacement length
y_0	initial value of y
α	extinction coefficient
ε	absorbance
ε'	actual energy absorbance
μ	dynamic viscosity
ρ_l	liquid density
ρ_g	gas density
σ	surface tension
ς	turbidity
τ	relative time
$\Delta\tau_{pp}$	peak-to-peak relative time
ω	characteristic frequency

Subscript

dod	n-dodecane
in	at inlet
out	at outlet
w	water

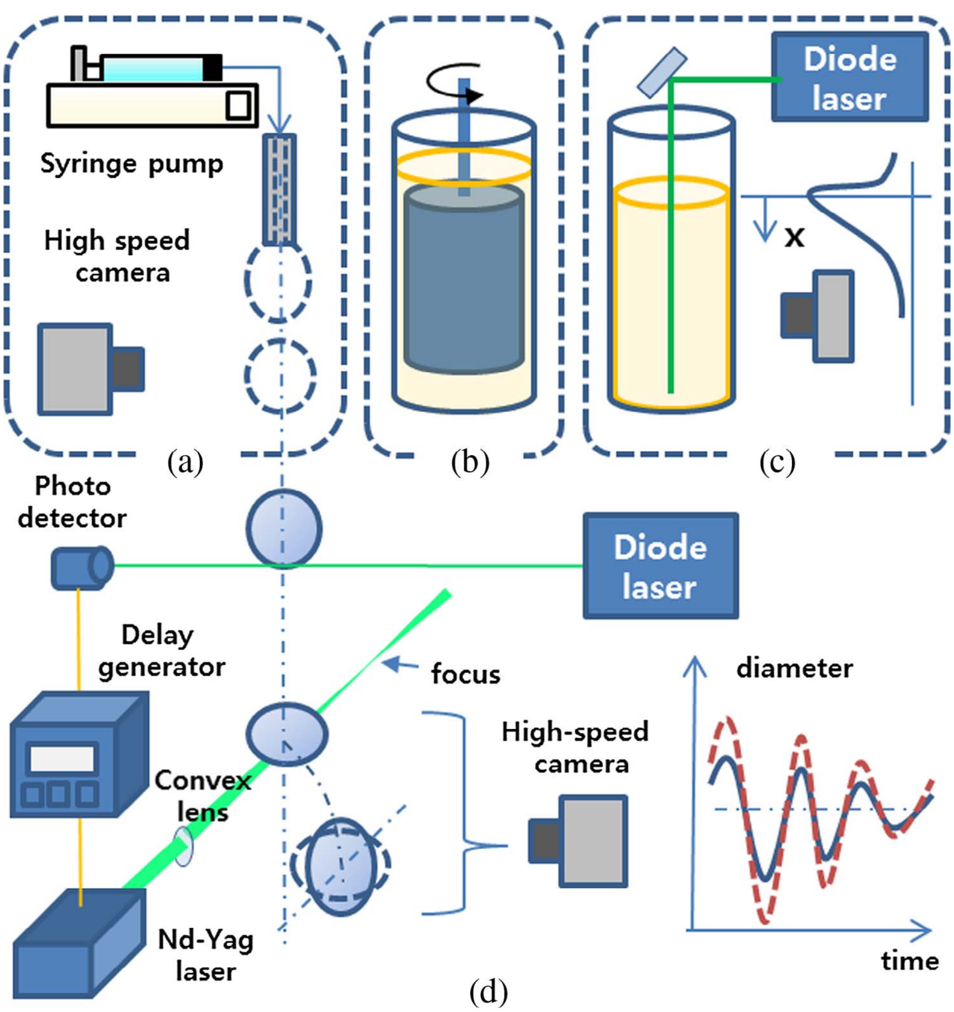

Fig. 1. Experimental method: (a) Surface tension, (b) Dynamic viscosity, (c) Light scattering ratio, and (d) Dynamic measurement of surface tension, viscosity, and light absorbance.