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# Using Planar Laser Induced Fluorescence to explore the mechanism of the explosive disintegration of water emulsion droplets exposed to intense heating

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ABSTRACT

In this paper, we study the boiling of heated water emulsion droplets in the air flow at a temperature of 20–800°C. The relative volume concentration of the flammable components in the emulsion varies from 10% to 70%. We explore the unsteady temperature fields of droplets using a contactless optical diagnostic technique, *Planar Laser Induced Fluorescence*, with a cross-correlation system featuring a camera, a laser, a synchronizer, and the *ActualFlow* software. *Rhodamine B* acts as a fluorophore. We also use a high-speed video camera (up to $10^5$ fps) and continuous automatic tracking algorithms (*Tema Automotive* software) to record the rates of heating and evaporation, as well as transformation of droplet surfaces. We demonstrate the unsteady temperature fields of droplets and three modes of their boiling and breakup. These differ in the number and dimensions of the emerging droplets as well as the durations of the main stages. The temperature differentials at the *water – flammable component* interface are determined corresponding to three boiling and breakup modes. We show that the third mode provides the greatest number of fine droplets (no less than 200) if the heating temperature exceeds 400°C and the concentration of the *flammable component* is over 66%. The temperature at the phase interface reaches 100 °C–125 °C before disintegration, and the droplet heating times before explosive breakup may vary from 0.1 s to 10 s. Finally, we analyze how the temperature, additive concentration and droplet size affect the conditions and characteristics of these modes.

## 1. Introduction

Thermal and flame water cleaning from unspecified impurities has received a new impetus to progress over the last years. Recent research findings (in particular, [1–5]) provide insight into the conditions and main properties of processes involved in boiling and explosive breakup of droplets of liquids, solutions, emulsions, and slurries. One of the most appealing ways to boost the efficiency of thermal cleaning is the explosive breakup (disintegration) of droplets. Volkov et al. [6] suggest an approach to intensifying the heating and evaporation of water slurry droplets through their explosive boiling and breakup. The main idea behind the method is as follows [6]. Due to solid or liquid additives, phase interfaces emerge in water droplets. They work as sources of bubble nucleation under strong heating. Enough energy accumulates at the phase interfaces to cause a rapid increase in temperature in this area. Due to rapid growth of bubbles and their fusion, the droplet expands and its surface transforms. These processes take a short time and are accompanied by a single droplet turning into a cloud of small ones (aerosol). The experiments in Ref. [7] focus on the processes involved in the formation of such clouds. The authors [7] refer to these processes as the *explosive breakup*. However, temperature gradients necessary and sufficient for explosive breakup have yet to be determined because of the limitations of the current measurement systems and vaporization models. Furthermore, it follows from review paper [1] that the mechanism and the main characteristics of fast-paced boiling and explosive breakup of superheated emulsion and slurry droplets are difficult to determine using conventional vaporization models (e.g. Refs. [8–10]). Especially challenging are the rapid evaporation and boiling of multi-component liquids (fuel solutions and emulsions), since a large group of components evaporate simultaneously [1].

Recent years have seen the rapid development of optical methods of high-speed measurement used to obtain the parameters of gaseous, fluid and heterogeneous media [11–17]. The method of choice to determine the unsteady temperature field of an evaporating heterogeneous water emulsion droplet is *Planar Laser Induced Fluorescence* (PLIF). In Refs. [18–23], the authors outline the key benefits and barriers to the use of PLIF when determining the temperature fields of liquids. The preliminary analysis has shown that using PLIF for

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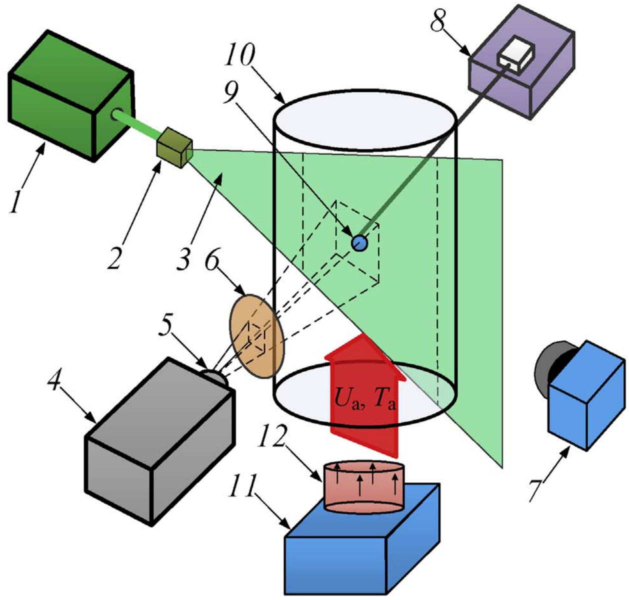
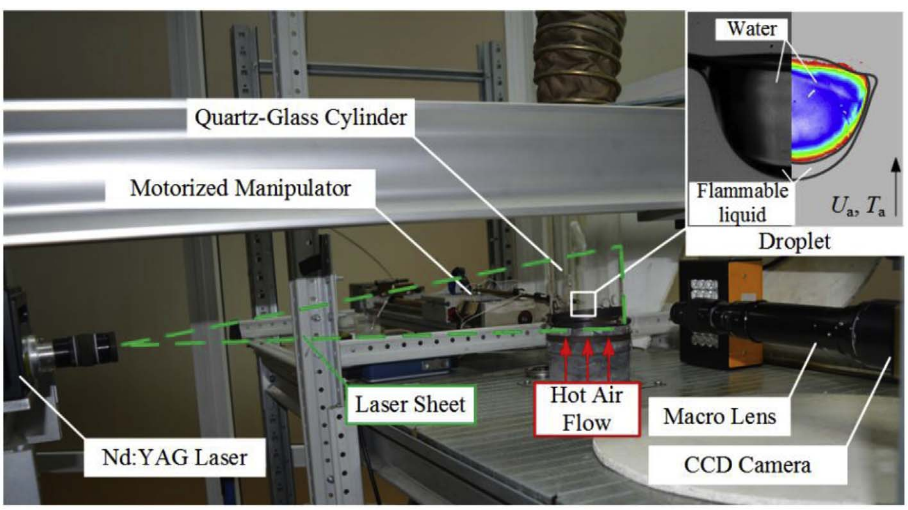



a




b

**Fig. 1.** Schematics (*a*) and photograph (*b*) of the setup: *1* – pulsed laser; *2* – laser optics; *3* – laser sheet; *4* – cross-correlation digital camera; *5* – macro lens; *6* – light filter; *7* – high-speed CMOS video camera; *8* – motorized manipulator; *9* – droplet; *10* – transparent quartz-glass cylinder; *11* – air blower; *12* – air heater.

measuring the unsteady temperature field of an evaporating droplet will provide the necessary experimental information on the temperature gradient from the center to the surface of a droplet as well as from the latter to the phase interface. Using PLIF will make it possible to determine the temperature gradients at the phase interface, necessary for the breakup of heterogeneous water emulsion droplets and enhancement of their evaporation.

The purpose of this work is to experimentally determine the unsteady temperature fields of heterogeneous water emulsion droplets under high-temperature heating followed by boiling and explosive breakup to form a cloud of fine aerosol.

## 2. Experimental setup and procedure

### 2.1. Main elements of the experimental setup

Fig. 1 presents a schematic representation and a photograph of the experimental setup. The experimental system consists of the following key equipment: high-speed *Photron SA 1.1* CMOS video camera (recording frequency up to $6{\cdot}10^5$ fps, maximum resolution 1024 × 1024 pixels); *ImperX B2020M* cross-correlation digital camera (recording frequency 25 fps, resolution 2048 × 2048 pixels); *Nicon* macro lens (focal length 200 mm); a set of light filters (600–10 nm) and fluorescent dyes; dual pulsed Nd:YAG *Quantel EverGreen 70* laser (wavelength 532 nm, maximum energy 74 mJ); a lens for generating a laser sheet with an opening angle of 8°; motorized manipulator based on a servo drive and a linear module (with *MotoMaster software*); *National Instruments 9213* analog input module (card) with a Pt-(Pt-Rh) fast-response thermocouple (temperature measurement range 0–1600 °C, error ± 1 °C, thermal time lag 0.1 s, junction diameter 0.1 mm); *Leister CH 6060* air blower (air velocity 0–5 m/s); *Leister LE 5000 HT* air heater (temperature range 20–800 °C); quartz-glass heat-resistant cylinder (inner diameter 0.1 m, wall thickness 0.003 m); personal computer with *Tema Automotive software* to track dynamic objects as well as *ActualFlow* and *PLIF Kit* software.

### 2.2. Parameters of hot air flow

Hot air flow with controlled parameters (temperature $T_a$, air velocity $U_a$) was generated by the air blower and air heater. The system