Fire Safety Journal 70 (2014) 61–70

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Experimental investigation of atomized water droplet initial parameters influence on evaporation intensity in flaming combustion zone

Olga V. Vysokomornaya, Geniy V. Kuznetsov, Pavel A. Strizhak*

National Research Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk 634050, Russia

ARTICLE INFO

Article history:
Received 5 April 2014
Received in revised form
25 August 2014
Accepted 31 August 2014
Available online 18 September 2014

Keywords:
Water
Droplets
Evaporation
Flame
High-temperature gases
Fire fighting

ABSTRACT

Experimental investigation of integral characteristics of typical extinguishing liquid (water) droplet evaporation in flaming combustion zone was carried out with varying of their basic initial parameters (sizes, relative concentration in a flow or current, temperature, screenings content, structure homogeneity, motion velocities into a flow). Optical methods of two-phase and heterogeneous gas–vapor–droplet mixtures diagnostics (“Particle Image Velocimetry” and “Interferometric Particle Imaging”) were employed. The significant influence of temperature, sizes, structure and droplet concentration in the atomized water flow on evaporation characteristics was determined. The sufficiently moderate influence of salt admixtures on water evaporation conditions at its finely divided injection in the flame was established. Some modes of water droplet motion in the flame area were indicated according to their moving velocity and sizes, and combustion product velocities too. Values of water droplet basic parameters were calculated. These parameters provide the maximum evaporation in the flame zone with intended sizes.

1. Introduction

“Vapor-water curtains”, “water fog”, “vapor–droplet mixtures”, and flows of atomized by special way liquids (in particular water and its emulsions) are characterized by improved efficiency at fire extinguishing and fire response in comparison with large volumes of non-atomized water [1–14]. As a consequence the operations of traditionally used fire-extinguishing systems remodeling are conducted intensively. It is for the purpose of making possible the finely divided atomization of extinguishing liquid in the flame area.

Numerical and experimental investigations made in recent years [1–14] showed that the evaporation is intensified significantly, oxidant and combustion products are forced by forming vapor flow, temperature in the flame zone is decreased. It happens under specialized atomization of extinguishing liquids in the flaming combustion zone. As a consequence the fire source is localized under employment of different mechanisms. It is evident that it is possible to intensify the extinguishing liquid evaporation in the flame area not only at its droplets pounding. The complex analysis of water droplet basic parameters influence (in particular temperatures, screenings content in them, relative concentration in atomized water flow, velocities and initial sizes) on integral characteristics of concerned processes is of some interest. Furthermore, it is expedient to study the combustion product velocities influence on water droplet evaporation intensity in the flaming combustion zone.

It is sufficiently difficult (especially at droplet sizes up to 500 μm) to accomplish the respective investigations with usage of known physical and mathematical models (for example [9,10]) for a large water droplet aggregate in a flaming combustion zone. Experiments [11–14] showed that it is expedient to use the optical methods of two-phase and heterogeneous gas–vapor–droplet mixtures diagnostics (in particular “Particle Image Velocimetry” and “Interferometric Particle Imaging”) for analyzing the regularities of concerned processes under high-temperature (more than 1000 K) conditions [15–18].

The goal of the present work is to study experimentally the basic parameters of typical extinguishing liquid (water) droplets influence on the intensity of their evaporation in the flaming combustion zone and also to determine the values of these parameters when it is possible to provide the maximum evaporation.

2. Experimental technique

The experimental setup was used. Its scheme is on Fig. 1. The basic elements of the setup are: cross-correlation digital

---

* Corresponding author.
E-mail address: pavelspa@tpu.ru (P.A. Strizhak).

http://dx.doi.org/10.1016/j.firesaf.2014.08.016
0379-7112/© 2014 Elsevier Ltd. All rights reserved.

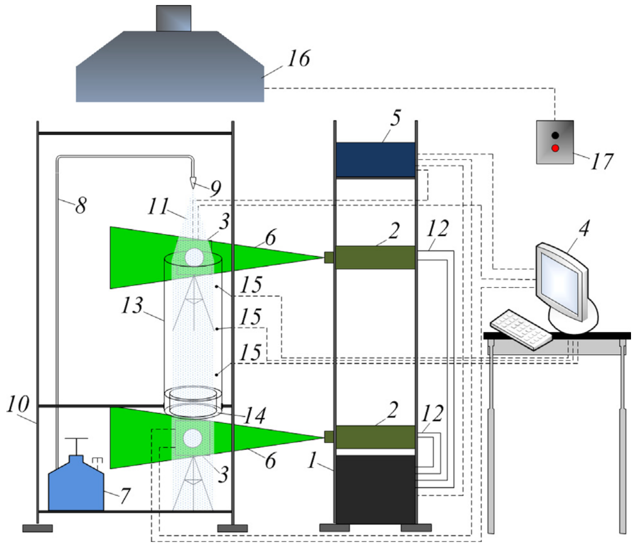

Fig. 1. A scheme of experimental setup: *1*—laser generator; *2*—double pulsed solid-state laser; *3*—cross-correlation digital camera; *4*—PC: personal computer; *5*—synchronizer of PC, cross-correlation digital camera and laser; *6*—light "pulse"; *7*—vessel with experimental liquid; *8*—channel of experimental liquid supply; *9*—atomizer (dosing device); *10*—mount; *11*—experimental liquid droplets; *12*—cooling liquid channel of laser; *13*—cylinder from a heat-resistant translucent material; *14*—hollow cylinder; *15*—thermocouples; *16*—replacement exhaust system; *17*—control panel of replacement exhaust system.

camera (figure format—2048 × 2048 pixel, frame frequency—1.5 Hz, minimal delay between two sequence figures—5 μs), double pulsed solid-state laser (with active sphere "yttrium aluminum garnet" and neodymium additives, wave-length—532 nm, minimum energy in impulse—70 mJ, maximum impulse time—12 ns, recurrence frequency—15 Hz), synchronizing processor (maximum signal sampling—10 ns).

Water with special inclusions—"tracers" was used as a studied extinguishing liquid. "Tracers" are the mixture (0.5% in weight) of titanium dioxide nanopowder. Inclusions were added for contrast increase of videograms received with cross-correlation digital camera. Particles TiO_2 were chosen as a "tracers" because they do not dissolve in water and practically not influenced on water evaporation characteristics [11–14]. Particles of TiO_2 with characteristic sizes from 80 nm to 130 nm (chosen range is due to claims [15–18] of panoramic optical methods PIV and IPI) were used in experiments.

Extinguishing capability of water is characterized by two parameters: flame of energy which is spent for heat-up of water droplets and implementation of follow endothermal phase transformations; concentrations of water vapors which displace the oxidants from the combustion zone. Heat-up of water droplets is determined by the main thermophysical properties—thermal conductivity, thermal capacity and density. It is obvious that at a relative mass concentration of TiO_2 particles equal to 0.5% the thermophysical properties of water are not changed significantly. So velocities of phase transformations (correspondingly the concentrations of force water vapors) of water droplets under investigation are not changed at these concentrations. In experiments [11–14] the specialized estimations of this effect were conducted.

TiO_2 particle cloud at some part of droplet which would lead to significant deviations of droplet evaporation velocity (and extinguishing capability of water) was excluded in the experiment due to using specialized mixing systems in the vessel with water *7*. Inertial forces have had the effect on particles of TiO_2 during droplet motion. These inertial forces are oriented (judging by videograms of experiments) in all three coordinate directions and are due to third dimensional droplet deformation during the flight. If "settlings from particles" would formed in the bottom part of droplet then this effect would be well shown at videograms of experiments (but these effects were not registered). So "tracer" particles of TiO_2 with chosen concentration can't influence significantly both on integral characteristics of droplet evaporation and on extinguishing capability of water.

The variety of water droplet sizes was accomplished during experiments in typical for many supplements (for example [4–14]) range $0.01 \le R_m \le 0.4$ mm, and also a relative droplet concentration in a flow of atomized liquid ($0 < \alpha_m < 1$). The condition radius R_m was taken as a characteristic droplet size (similar to experiments [11–14]), because water droplets took the form of ellipsoids during motion in the gas flow. From 7 up to 10 maximum diameters of such droplets were calculated and average values were R_m determined. Due to that fact that it can't be the "ideal" spheres under conditions of phase transformations for all that it is expedient to call the characteristic radius R_m like conditional one.

The volume concentration of water droplets in a gas area in the experiments was 0.001–0.0012 (m^3 of water droplets/m^3 of gas). The choice of this range was conditioned by optical methods PIV and IPI limitations in a number of "tracer" particles in one pixel and droplet image interference [15–18].

The initial temperature T_w of atomized water was changed in a range of 293–323 K with heat chamber usage [11–14]. The initial velocity of water droplets was assumed by specific heat chamber and dosing device (Fig. 1) in a range of $0.1 < U_m < 5$ m/s.

Velocity, sizes, dispersion and droplet atomization angle were assumed in conducted experiments and were supported as identical for a series of experiments. For these, the emanative channel (conductor) was tuned on the dosing device *9* and required pressure in vessel *7* was set. Then it was conducted up to 10 test atomizations of liquid with measurement of droplet motion velocities, their sizes, dispersion and atomization angle. To determine the listed parameters the panoramic optical methods PIV и IPI [15–18] were used.

Velocities of droplets with various sizes are changed differently during displacement [11–14]. To exclude the influence of this factor on the processing results of conducted experiments the distance from dosing device *9* to zone of high-temperature gases (inlet of droplets into cylindrical channel *13*) was decreased.

Also the NaCl nanoparticles were added into the water (relative concentration γ was varied in a range of 0–0.1 by weight) to study the typical salt admixtures influence on evaporation characteristics.

Combustion products of typical liquid fuel—kerosene were used in the cylindrical channel *13* to form the flow of high-temperature (more than 1000 K) gases with requirement characteristics (temperature, motion velocity, component composition). The liquid combustion substance was filled up in the hollow cylinder *14* base of the experimental setup (Fig. 1) similar to [11–14]. The kerosene ignition was triggered before the start of successive experiment. Its combustion products temperature was controlled by chromel–alumel thermocouples (the range of measured temperatures 273–1373 K, permissible deviation $\Delta = 3.3$ K) at different height marks (0.15 m, 0.5 m, 0.85 m) of the channel *13*. Combustion products motion velocities in the channel *13* were changed in the range $0.1 < U_g < 2$ m/s with the usage of replacement exhaust system *16* (Fig. 1).

Velocity U_g of gases motion was calculated in separate experiments which were previously to experiments with force droplets of liquid. To control velocities of gases in channel *13* before the injection of liquid droplets the particles of titanium dioxide nanopowder (from 5000 to 7000 particles for carrying-out of requirements of minimal number of "tracers" in computational video frames domain) were forced into it. Velocity fields of "tracers" and their channel radial distributions were recorded. At the attainment of conditions relatively to steady (deviations of values of "tracers" velocities did not exceed 7% radially) gases