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How to improve efficiency of using water when extinguishing fires through the explosive breakup of drops in a flame: Laboratory and field tests

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ABSTRACT

The study reports results of the experimental research on the explosive breakup of heterogeneous water drops in high-temperature (800–1200 K) conditions typical for fires. The temperature of heating conforms to mean values for large forest fires. We use water drops containing special-purpose inclusions, such as 1–3 mm solid opaque particles (natural graphite). Laboratory experiments enable us to define conditions for the intensive fragmentation of such the drops. This process is characterized by formation of droplets of smaller size. The number of fragments can be from several ones to several hundreds. As a result, the evaporation surface area of liquid increases 3–15-fold during such the fragmentation. This effect is important for the most complete water evaporation in a flame during the fire extinguishing process. In such a case, the maximum temperature reduction in a flame zone becomes possible by absorption of heat of phase change. Field tests show that the usage of suspensions based on water facilitates a dramatic drop in temperature in a flame zone by 40–70 K as compared to water without additives. Consequently, fire extinguishing occurs during shorter time and by using smaller volume of water. Both the characteristics can decrease by 30–40% as compared to water without additives.

1. Introduction

Taking into account the limited capacity of aircraft, which are usually applied to extinguish the large forest fires, water volume supplied into fire zone does not exceed 20–30 thousand m^3. Ministry of Emergency Situations of Russia uses fairly big aircraft (in particular, IL-76) with the capacity of 30–40 tons of water. Firefighters in Canada and the USA utilize groups of small aircraft with the capacity of each one from 3–4 tons to 10–15 tons.

The control of water discharge is critically important for the effective suppressing a fire because rates of spreading the latter are extremely high and can reach dozens of meters per second. In other words, during the repeated flight of aircraft, the fire area can increase many times in case of its incomplete suppression during the first flight. Moreover, there are certain difficulties with searching of close natural bodies of water for the aircraft loading. Thus, due to these problems the water management becomes relevant when extinguishing fires.

When suppressing large forest fires, most often water is used without any additives, from nearest waterbodies. The known additives (phlegmatizing agents, retardants, chemical agents) make the fire extinguishing process very expensive at large volumes of water. Large fires require the high volume of such additives. Moreover, these additives often have the complex chemical composition and harm forests during some time after their discharge into a fire. Therefore, investigations on processes of fire extinguishing by water without the special-purpose chemical agents (liquid or solid) become critically urgent. Based on the state-of-art concepts on these processes we can conclude that, primarily, the important thing is to optimize a water spraying into a fire zone.

To date, experimental and theoretical investigations [1–4] were performed to reveal the optimum drop size, dispersity of water flow when supplying in a combustion area. Also, the analysis of results allows establishing the limiting size and threshold velocities of water drops. These characteristics conform to an entrainment of drops from a fire zone by the counter motion of combustion products. Furthermore, the significant effect has a wind load.

The local discharge of water is fairly often applied to minimize the entrainment of water drops from a fire zone [3,5]. However, as a rule, the usage of this method leads to a water surplus on the local

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zone and the ineffective suppression of a combustion. The analysis shows that in such a case it is possible to save the considerable volume of water and redistribute it among other combustion areas. Therefore, it is important to improve spraying water in a flame, i.e. to provide conditions for the fragmentation of large drops in a flame and the complete evaporation of small droplets formed in a combustion area after fragmentation. Such the approach will contribute to enhancing a water use efficiency when fighting large forest fires.

There are several steps for researchers and engineers to undertake when developing a new firefighting technology. The first stage is to define the idea that will determine the novelty of the technology under development, and to formulate hypotheses for possible heat and mass transfer processes, phase transformations and chemical reactions during firefighting. After that, all the hypotheses are experimentally tested in the laboratory conditions and on specialized firefighting ranges. Considering the obtained experimental results, all possible improvements to the technology are implemented, followed by the second round of experiments. The development of physical and mathematical predictive models begins as soon as we provide the decent repeatability of the results and effective fire suppression with less water and time consumed. The very same approach is used for technologies discussed in Refs. [4,6].

Study [4] proves how it is important to intensify water evaporation in a fire zone for maximum decreasing a temperature. Such the problem can be solved by increasing water evaporation area, i.e. surface area of drops. There exist several methods how to do it. The most widely spread one is a spraying water. However, in case of forest fires to implement this process is almost impossible even by using modern aircraft. Study [6] offers an alternative idea is to spray heterogeneous water flows in a fire zone. This approach provides the fragmentation enhancement of water drops in a flame by adding foreign inclusions: nonmetallic and metallic particles. However, within the proposed idea on the explosive breakup of heterogeneous drops [6] to date, there are no valid experimental data to explain this phenomenon, including the results of field tests.

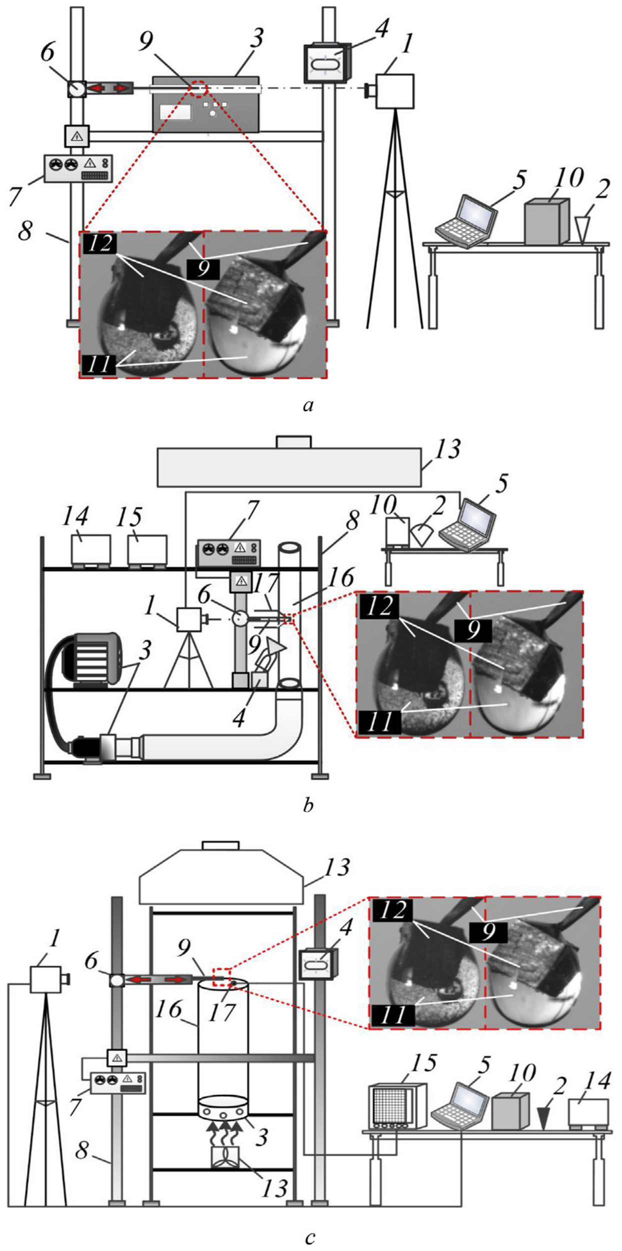
The conditions for the performance of the experiments when interacting water drops with the high-temperature gaseous environment and the heated wall [7–13] considerably differ. In particular, the gaseous environment considers different mechanisms for the heating, namely the convective, conductive and radiant heating. For the drops on the hot wall or substrate, the heating by conduction plays a major role. The formation of the vapor layer between the heating surface and the drop plays the particular role. The specific features for the formation of such buffer vapor layers are typical of the conditions for heating of emulsions, solutions and suspensions on the heated walls. The interfacial boundary area is much larger than the contact area between the water drop and the wall (substrate). Therefore, by using the known evaporation models of the water drops on substrates and heated walls, it is difficult to predict characteristics for the high-temperature evaporation of drops in a flame and streams of combustion products. Consequently, the significance of obtaining the experimental data on the high-temperature evaporation of drops of water, emulsions and suspensions in gaseous environments is obvious. Such conclusions can be drawn from the analysis of conditions and characteristics for the evaporation of drops of the typical fuels [14] in the high-temperature gaseous streams, on surfaces of substrates and walls.

The aim of this work is to define experimentally conditions of the multiple growth of the evaporation surface area of liquid in a flame, when the explosive breakup of water drops containing solids occurs.

2. Experimental setup and methods

Fig. 1 illustrates three schemes of test benches applied for the experimental research. In respect of the equipment configuration the three test benches is rather similar. The main distinction between them is in an application of different devices for generating high temperature area. Thus, Fig. 1, *a* presents a test bench where the tube muffle furnace heats subjects of research (heterogeneous water drops), Fig. 1, *b* – a test bench with the air heater, Fig. 1, *c* – a test bench with the fuel burner, i.e. the combustion products of fuels heats heterogeneous water drops.

The explosive boiling effect with consecutive breakup of



a

b

c

Fig. 1. Schemes of test benches with tube muffle furnace (*a*), air heater (*b*) and fuel burner (*c*): high-speed camera (*1*); dosing device (*2*); muffle furnace/air heater/fuel burner (*3*); spotlight (*4*); personal computer (*5*); minirobotic arm (*6*); power supply for the minirobotic arm (*7*); mount (*8*); ceramic rod (*9*); analytical balance (*10*); drop of water/suspension (*11*); solid particle (*12*); air flow system (*13*); manufacture of particles (*14*); data acquisition device (*15*); cylinder of quartz (*16*); thermocouple (*17*).