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Localization conditions for model ground and steppe fires with the use of barrier lines

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Abstract Fires in the immediate vicinity of human settlements result in the most devastating social, economic and environmental consequences. This especially goes for forest and steppe fires. The localization of model ground forest and steppe fires with the use of a protective water line in the form of a moistened layer of material before the main combustion front has been studied experimentally. The volume of water that allows localizing the propagation of flame burning and thermal decomposition fronts has been registered. The values of the integral criterion, irrigation density (specific consumption), have been calculated. The rates of thermal decomposition and flame combustion of the materials under study at different air flow rates (to reproduce the wind factor in real conditions), as well as the influence of the latter on the conditions and characteristics of the localization process have been compared.

***Keywords*:** Steppe fires; ground forest fires, combustion localization; protective water line; irrigation density.

1. Introduction

Most experts in the field of fire fighting and the scientific community have come to the conclusion that in real practice it is extremely difficult to completely suppress combustion in large areas [1–4]. In such conditions, it is advisable to focus on the development of technologies for localizing the combustion centers [5]. Among the modern methods of localization of ground forest and steppe fires the most often used are the so-called barrier lines in the form of trenches, ditches, and glades. The simplest scheme involves moistening a layer of forest fuel material (FFM) of a given width, length and depth (often considered as thickness) before the combustion front [5]. However, there is still little experimental data on the minimum dimensions of the lines and volumes of water, providing localization of steppe and grounds forest fires [5].

The objective of this work is to substantiate by experimental results the necessary and sufficient conditions for the localization of the combustion front of model ground and steppe fires using a water barrier line.

2. Experimental setup, models of fire centers and methods

The realized experiments were based on typical fuel materials: pine needles, birch leaves, a mixture of FFM (birch leaves –25 %; pine needles – 15 %; and branches of hardwoods – 60 %), and the bulk of herbaceous plants. Parameters of a sample of fuel material (humidity, density of filling, and dimensions) were controlled similar to the method from [5]. The main difference between the present work and the experiments of [5] was the comparative analysis of the conditions and characteristics of the localization of FFM sample burning. This analysis aimed at studying the parameters of effective localization of such burning when applying the protective water line before the front of pyrolysis and flame combustion. The weight of the samples was about 45 g. The material was placed evenly in a metal pallet with dimensions: a length of 300 mm, a width of 200 mm, and a depth of 40 mm. The density of the sample in all experiments was maintained average (30–40 kg/m^3) relative to the possible range in real practice (due to long-term compaction of leaf fall).

The scheme of the experimental setup is shown in Fig. 1. There is also an air blower for reproducing the wind factor. The velocity of the air flow U_a varies from 0.5 to 3 m/s. From the side of the air blower the sample combustion is initiated over its entire width using piezo-ignition elements (Fig. 1). Before the burning front (i.e. a few minutes before) the protective line with fixed sizes and water volume is wetted down. Three thermocouples (platinum-rhodium-platinum, temperature range of 50–1500 ^{0}C, systematic measurement error of 1.5 ^{0}C, and thermal delay time of 0.1 s), located at different depths in the layer of FFM, thermal imager (Testo 885-2) and video camera (Sony HDR CX240E) are used to register the conditions of propagation of the fronts of flame combustion and pyrolysis over the sample, braking due to the barrier line and the subsequent complete cessation of chemical reaction in the sample. The criterion is the reduction of temperature in the material layer below the value corresponding to the beginning of thermal decomposition, and for all materials the total value of about 150 ^{0}C is taken. The size of the barrier line and the amount of used water vary to determine the necessary and sufficient conditions for the localization of FFM combustion.

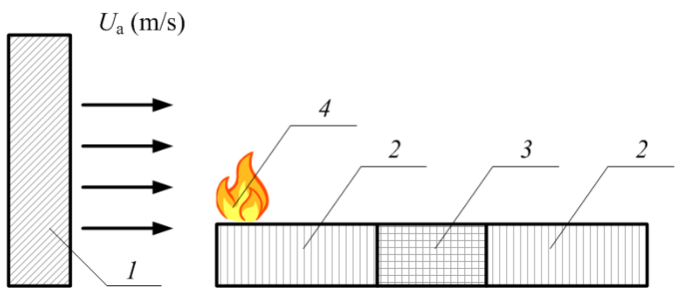

Fig. 1: Experimental scheme: *1* – air blower, *2* – dry FFM, *3* – barrier line; *4* – initiation of combustion.

The average size of aerosol droplets R_d=0.08–0.1 mm to generate a line [6]. The sizes of droplets to be injected into the zone of the barrier line are controlled in advance, i.e., in test experiments, using a high-speed cross-correlation complex and optical methods of registration (“Shadow Photography” and “Particle Interferometry Imagine”), described in [5].

3. Results

Comparative analysis of the readings of thermocouples, thermal imager and video cameras has revealed that the fronts of pyrolysis and flame burning in the sample of leaves propagate only over the surface layer. Deep layers of the sample practically do not enter into reactions of thermal decomposition (this determines the minimum time of localization of combustion of such samples as in Fig. 2, since it is sufficient to suppress the reaction in the near-surface layer). In the experiments with pine needles, effects of rather rapid spread of pyrolysis fronts into the deeper layers were recorded. As a result, the complete cessation of combustion required longer times of localization (Fig. 2). For a mixture of materials, this parameter was maximal due to a significant role of branches having high combustion heat. Therefore, burnout rates (Fig. 2) and amounts of water necessary to stop burning (Fig. 3) differed significantly.

Dependences shown in Fig. 2 illustrate the influence of the structure of fuel material (forest and steppe) on the duration of localization of respective fronts. The most time-consuming processes are the suppression of pyrolysis of dry grass and a mixture of FFM. This is obviously due to their high porosity and high permeability. Moisture, supplied to the surface of the layer of even rather thick grass, quickly passes through it and is absorbed by the soil (in the experiments it went into the collector under a pallet of fuel material). Mixtures of leaves, needles and branches also have the highest (among he considered materials) porosity and, accordingly, permeability. This is due to significantly different characteristic sizes of the elements of these mixtures (needles – fractions of millimeters, leaves – several millimeters, and branches – tens of millimeters). The mixing of such essentially inhomogeneous components, as a rule, results in the formation of samples with very high (compared with other materials) porosity. Water passes through the pores of FFM for a small interval of time and does not have a rapid effect on the combustion of the layer of material adjacent to the line of moistened material (barrier line).

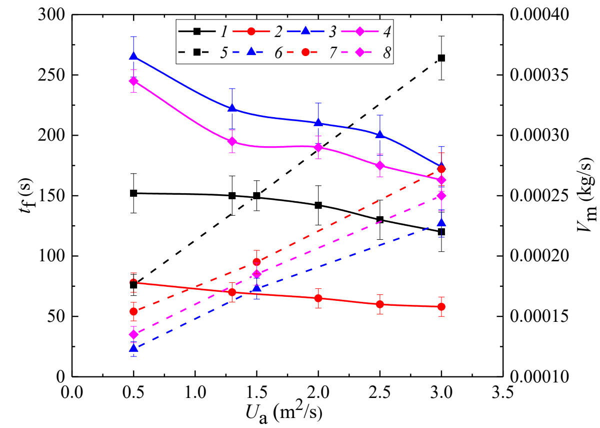

Fig. 2: Dependences of time of full localization of thermal decomposition and combustion *1–4* (t_f) and mass flow rate of FFM burnout (including flame combustion and thermal decomposition in the layer of the forest litter) *5–8* (V_m) on air flow velocity when considering different types of FFM: *1*, *5* – needles, *2*, *7* – leaves, *3*, *6* – a mixture of FFM, *4*, *8* – herbaceous plants.

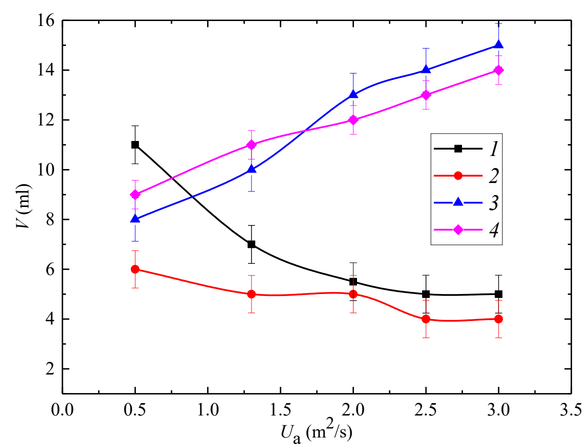

Fig. 3: Dependence of the minimum volume of extinguishing liquid necessary to suppress the flame combustion and thermal decomposition of FFM on air flow velocity at burning different types of FFM: *1* – needles, 2 – leaves, *3* – a mixture of FFM, *4* – herbaceous plants.

The results of experiments presented in Fig. 2, 3 give grounds for a reasonable conclusion that the effectiveness of the water barrier lines substantially depends on the type of forest, and this factor should be taken into account when planning and organizing the processes of localization of ground forest and steppe fires. In particular, when summarizing the results of the experiments, the values of the so-called effective irrigation density (in essence, specific water consumption) are calculated to ensure the minimum sufficient conditions for localizing the combustion of the studied samples. More specifically, it has been found that herbaceous plants conventional for steppes are close to mixtures of typical FFM in their specific characteristics of combustion localization. The conducted experiments have also shown that the required minimum volume of extinguishing liquid (water) poured into the barrier line is greater for herbaceous plants than for other types of FFM at low air flow rates. When the flow rate increases, the volume of extinguishing fluid grows (however not as significantly as for the FFM mixture).

4. Conclusion

To localize pyrolysis in ground forest and steppe fires, it is necessary and sufficient to organize a specialized barrier in the form of a moistened layer of material before the combustion front. The size of such a line and the volume of water (and accordingly the specific water consumption or irrigation density) for needles and plant materials differ

To combat the combustion fronts at ground forest and steppe fires, the most feasible, safe and sufficient scheme of water spraying is the formation of a barrier line before the front. The main parameter of concern for specialists is the effective irrigation density, which ensures the required width, length and depth of the line. At that there are no significant restrictions on the time of water spraying in the line.

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