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Preserved boreal zone forest massif mass estimation during fire extinguishing by liquid aerosol

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Abstract. This study contains results of experimental studies into establishing the principles of decreasing the model of fire source mass when extinguishing the ground cover of deciduous and mixed forests by liquid aerosol. The experiments were carried out with typical forest fuels - birch leaves and mixed non-living components of temperate forest. Densities of forest fuel samples in a model of fire source were variated in the corresponding real practice ranges: 20.26–54.70 kg/m^3 for birch leaves and 27.54–72.18 kg/m^3 for a mixed forest fuel. Dimensions of droplets generated by the nozzle amounted to 0.01–0.12 mm. It is consistent with modern aerosol fire extinguishing systems. The dependence of the initial forest fuel sample mass on the remaining mass after ending of the pyrolysis reaction was established.

1. Introduction

Forest fires are considered to be spontaneous fire spread in forest zones with homogeneous and mixed vegetation [1]. As a result, after forest fires in Russia thousands hectares of forest are damaged and killed every year, forest animals and birds die, huge quantities of carbon dioxide and smoke are emitted into the atmosphere, residential settlements are destroyed, millions of rubles are spent from the state budget to extinguish forest fires and restore territories suffered from fire. The optimal way to eliminate the fire zone is a local discharge of quenching liquid from the side of the aircraft into the combustion zone [2]. Studies have shown [3] that with this approach to fire extinguishing most of the discharged liquid is absorbed into the ground. As a rule, it does not suppress the pyrolysis reaction in the soil covering of boreal zone. Only 5–7% of the total liquid volume intended for reducing the temperature during the combustion of forest fuel (FF) evaporates due to the termination of combustion and soil covering pyrolysis [3]. It is important to estimate the mass of FF, which can be preserved in the eliminating the bottom ignition process in the boreal zone.

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The aim of this study is to quantify the preserved forest massif during extinguishing the forest zone by liquid aerosol.

2. Experimental setup and procedure

Figure 1 shows the experimental setup used in carrying out experimental researches.

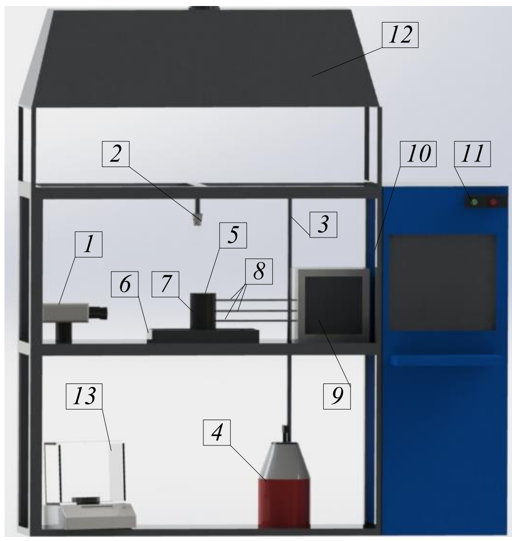

Fig.1. A scheme of experimental setup: *1* – high-speed video camera; *2* – spraying nozzle; *3* – water supply channel; *4* – water tank; *5* – FF; *6* – metal tray; *7* – cylinder with a FF; *8* – thermocouples; *9* – multichannel temperature recorder; *10* – workstation; *11* – control panel of turning on/off ventilation system; *12* – ventilation system; *13* – analytical microbalance.

Type-K needle thermocouples *8* (temperature measurement range 223–1473 K, accuracy ± 3 K, heat retention no more than 0.1 s) were used to measure temperature of the pervasive combustion process. Temperature readings were fixed on a multichannel recorder *9*. We realized quenching using spray nozzle *2* (droplets' size R_d=0.01–0.12 mm; irrigation density ξ_f=0.014–0.016 l/m^2·c; water consumption μ_w=0.00063 l/c). Liquid was supplied from the tank *4*. The speed of the droplet flow was determined using the high-speed video camera *1* and the "Actual Flow" software for processing the results of the experiments using optical methods of "Particle Image Velocimetry" (PIV) diagnostics. Dimensions of dispersed stream droplets were calculated by the IPI method [5].

Two groups of samples were used during researches. The first group included only birch leaves; the second group consisted of mixed non-living component of temperate forests with a following mass ratio: 25% birch leaves; 15% pine needles; 60% branches of hardwoods. We used distilled water (GOST 6709-72) for extinguishing the standardized fire. At the first stage of the experiment, FF sample was weighed on the analytical microbalance ViBRA HT 84RCE 13 with an accuracy of 10^{-5} g (mass m_{f0} was determined). After that, forest fuel was placed to the bottom of the cylinder. The initial weights and

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densities of samples are shown in figure 2. The initial weight of forest fuel was chosen so that its density varied from one experiment to another in a narrow range.

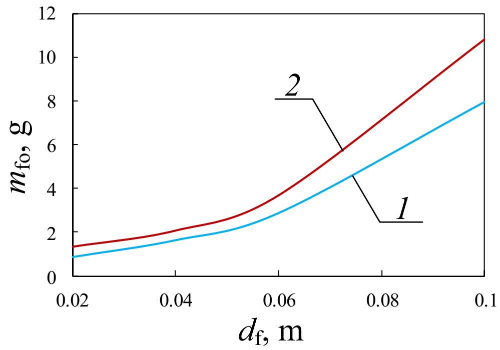
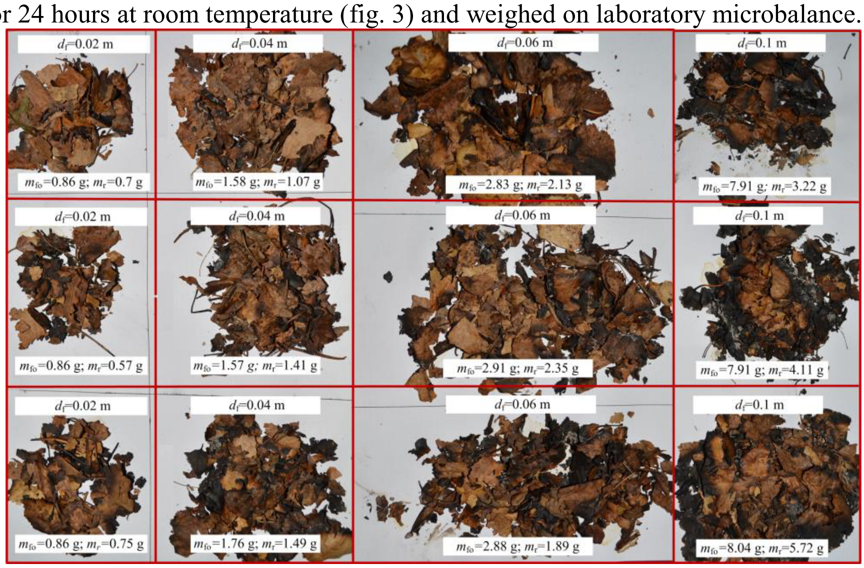


Fig. 2 Dependence of average FF weight (m_{f0}) on the original brazier diameter (d_f), with a constant height of forest fuel bed (h_f=0.04 м): *1* – birch leaves, *2* – mixed FF.

Ignition of the samples was carried out uniformly over the entire area of the open FF surface. We with used three piezoelectric gas burners simultaneously. For each model of fire source we conducted from 15 to 20 experiments. The standardized fires were extinguished by a liquid aerosol with a droplets' radius R_d=0.1–0.12 mm. Spraying continued until the complete suppression of thermal decomposition process Ending of this process was recorded visually and using thermocouple readings. After suppression of the pyrolysis reaction, the fraction (residue) of unreacted FF (m_r) upon extinguishing was dried for 24 hours at room temperature (fig. 3) and weighed on laboratory microbalance.



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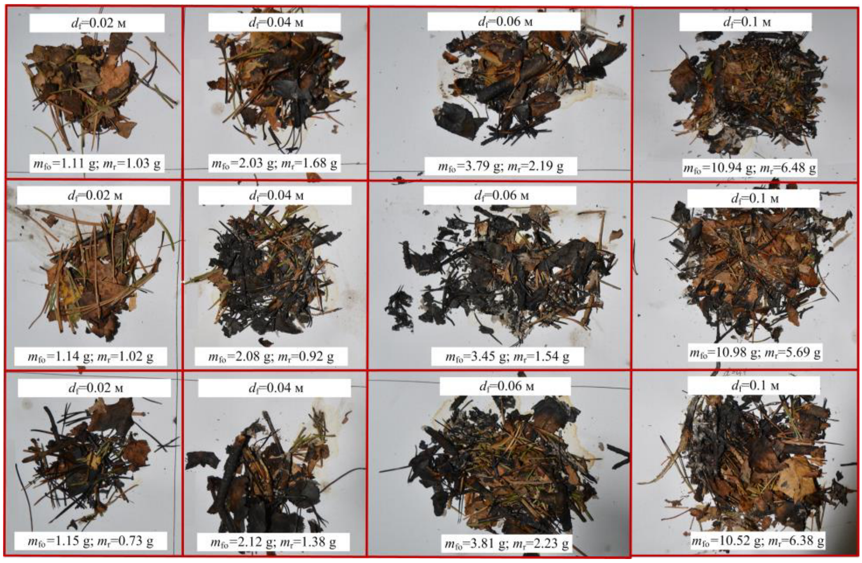

b

Fig. 3. Typical video records of the residual FF after extinguishing by liquid aerosol (R_d=0.1–0.12 mm): *a* – birch leaves, *b* – mixed FF.

3. Results and discussions

Figure 4 shows dependencies of the mass loss ($\Delta m = m_{f0} - m_r$) on initial mass of the sample in extinguishing.

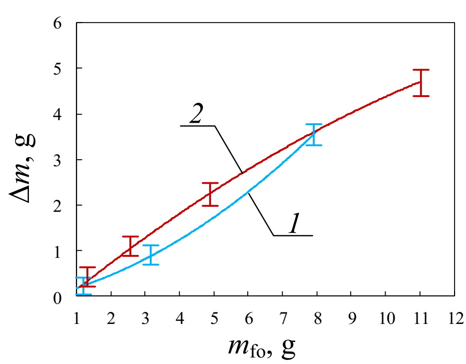

Fig. 4. Dependence of the parameter Δm ($\Delta m = m_{f0} - m_r$) on initial sample mass m_{f0} (Δm is parameter characterized FF mass loss during extinguishing by liquid aerosol): *1* – birch leaves, *2* – mixed FF.

An analysis of the location of the approximation curves of fig. 4 enable to conclude that the mass loss when extinguishing mixed FF is greater than for birch leaves (on 0.21–0.54 g). This effect may be due to the forest fuels covering structure. The area of birch leaves is larger than the area of needles and twigs. During extinguishing by a liquid aerosol, we observed water droplets accumulation on the birch leaves surface over a period of time. As a consequence, two extinguishing schemes were realized. These were blocking the oxidant entering the reaction zone and directly reducing the temperature of the decomposing FF bed – birch leaves. Because the differences in structure of samples with a mixed FF and birch leaves, water drops did not accumulate on the sample surface, but penetrated through the sample bed. The temperature of mixed forest fuel bed was reduced because of the water droplets evaporation. Penetrated into the pores of the sample water drops and the evaporation during the interaction of the products of thermal decomposition and the dropping stream – a cloud of water vapor was formed and displaced pyrolysis products.

Figure 5 shows dependencies of the remaining weights of FF (m_r) on the initial ones (m_{f0}). During comparing the initial mass of the sample and the remainder when extinguishing with a liquid aerosol (figure 4), it was established that a significant portion of the sample remained:

- for birch leaves - 53–83% of the initial mass of the sample (m_{f0});
- for a mixed FF- 54–85% of the initial mass of the sample (m_{f0}).

Figure 5 shows, that remaining mass increases with increasing of initial mass of FF. For birch leaves and mixed forest fuel there is an increase in m_r with a variation in the initial mass by 3.7 and 5.2 g, respectively. This effect may be explained by the heat content of the FF sample. During the experiments, the times of suppression the thermal decomposition reaction of forest fuel also increased with an increasing braziers' area.

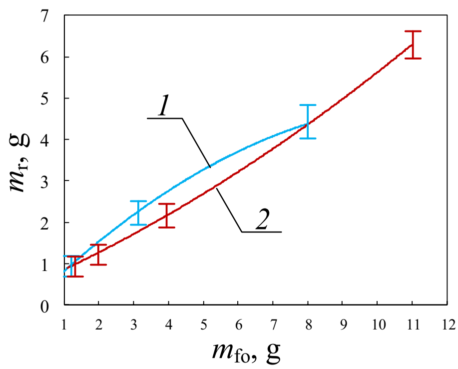

Fig. 5. Dependence of the remaining FF mass (m_r) on initial one (m_{f0}): *1* – birch leaves, *2* – mixed FF.

4. Conclusion

The obtained result leads to conclusion about the effectiveness of extinguishing forest fire by a liquid aerosol. Experimental studies allow us to establish that up to 80% of the initial mass of the soil covering in the boreal zone were preserved. The established principles reflect the positive outcome of forest fire extinguishing

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