

DETERMINATION OF THE MINIMAL AMOUNT OF WATER FOR EFFECTIVE SUPPRESSION OF THE THERMAL DECOMPOSITION OF FOREST COMBUSTIBLE MATERIALS

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Abstract. Forest fires are big problem for whole the world community. The development of new effective methods is needed to increase the efficiency of the firefighting. We have investigated experimentally the suppression of thermal decomposition of different typical forest combustibles using water aerosol. Droplet sizes were 0.02-0.2mm; the concentration - $3.8 \cdot 10^{-5}$ m³ of water/m³, the flow rate - 0.00035 l/s, flow velocity - 2 m/s. Registration of the aerosol propagation and interaction with combustibles was done by high-speed video camera using Shadow Photography and Particle Tracking Velocimetry methods. The effective water volumes for fire suppression were determined together with corresponding suppression times. The obtained results could be used for improvement of the fire-fighting technologies.

1 Introduction

Forest fires are sharp problem for whole the world community [1-3]. Determination of the minimal effective water volume for optimal fire-fighting is the key problem in this area. Hundreds or even thousands tons of water are usually needed for suppression of forest fire. However the usage of greater and greater water amounts does not correspond to acceleration of the forest fire suppression. There are some recommendations about water atomization before injection into the fire site to cover widest area. Though there is not an effective realization of the proposed ideas still.

The aim of this work is experimental determination of the minimal water amount that is enough for effective suppression of the thermal decomposition of forest combustible materials (FCM) during pre-defined time interval.

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2 The methods and the experimental setup

The scheme of the experimental setup is shown at fig. 1. The experiments were done in two stages. At the first one we have registered the details of parching of the model fire sites for each type of investigated FCM with determination of characteristic times t_b . At the second one, we have measured the fire suppression times t_e for model fire sites.

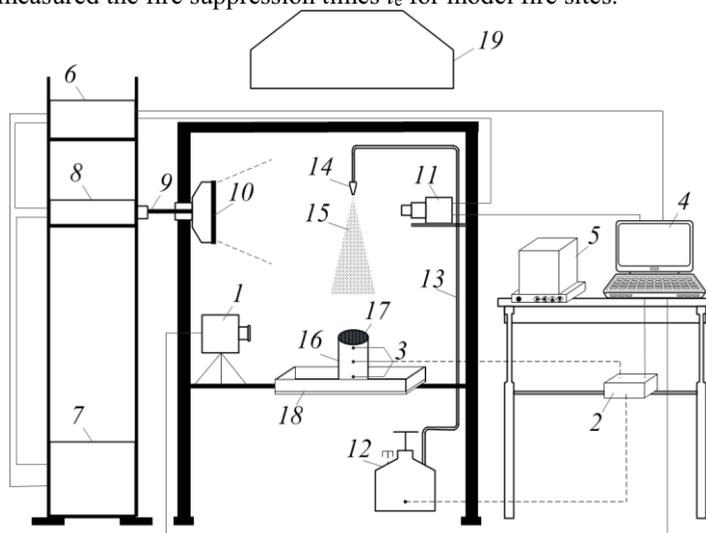


Fig. 1. Scheme of experimental setup: 1 – high-speed camera; 2 – high-speed analog input module; 3 – thermocouples; 4 – workstation (PC); 5 – laboratory microbalance; 6 – signal synchronizer; 7 – laser generator; 8 – solid double-pulse laser; 9 – optical fiber; 10 – diffuse screen; 11 – cross-correlation camera; 12 – container with water; 13 – water supply channel; 14 – spray nozzle; 15 – water mist; 16 – cylinder with forest fuel; 17 – forest fuel; 18 – metal tray; 19 – exhaust ventilation.

Four types of typical FCM were used during experiments: the birch leaves, spruce needles, aspen branches and the mix of them (with mass ratios 25 %, 15 % and 60%).

The first stage includes following steps:

- the cylinder 17 with portion of the FCM was installed onto fire-resisting tray 19;
- The needle-shape thermocouples 3 (K-type, with working range 223–1473 K, bias ± 3 K and time lag less than 1 s) were placed at three points on the symmetry axis of the cylinder 17 ;
- The time count was started from the moment of the ignition of the model fire site (with precision 0.01 s);
- The time gap between ignition and the moment of temperature decrease lower than the thermal decomposition threshold ($T_f \approx 370$ K) for all three thermocouples was estimated as total parching time t_b for chosen type of the FCM [4–6]. The stable exceed of the layer temperature above mentioned threshold was assumed as stable combustion of the FCM.

The second stage of the experiment (namely extinguishing of the fire site) consists of water aerosol feeding to the FCM portion surface. The water atomization was done by system consisting of nozzle 14, tank for pressurized water 12 and supporting fittings 13. The water feeding was started in 10-15 s after ignition (this time is enough for establishment of the thermal decomposition at whole the FCM portion). The water aerosol feeding was supported up to the moment of the total extinguishing of the model fire site.

The water droplet sizes were controlled by the optical diagnostic system [7] using “Shadow Photography” (SP) method. The droplet velocities were measured by the same system using “Particle Tracking Velocimetry” (PTV) method [8].

We assumed that the thermal decomposition of the FCM is started if the temperature measured by one of the thermocouples (which are installed at different heights of the FCM portion) was exceeding 370 K. The end of the thermal decomposition was assumed to the moment when the temperature of all the thermocouples become lower than 370 K that is lower than active pyrolysis threshold $T_{ef}=370$ K. The fig. 2 shows typical views of the FCM portions during the experiment: initial state, active combustion, at the fire extinction and after the fire extinguishing by the water aerosol.

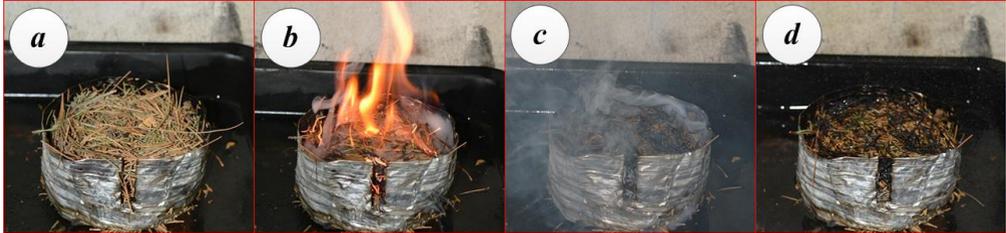


Fig. 2. Typical states of the spruce needles portion during the simulation for the forest fire extinguishing by aerosol flow (the layer thickness is $h_f=40$ mm, diameter $d_f=100$ mm). The states are: *a* – initial; *b* –during the active combustion; *c* –during the extinguishing; *d* – after the total fire extinction.

The water residue at the tray 19 (under the FCM portion) was collected after each experiment for analysis of its volume V_s . The water amount used for fire extinction was calculated by formula (1):

$$V_w = \mu_w \cdot t_e - V_s, \tag{1}$$

where μ_w is water flow rate and t_e is fire extinction time. There were 15-20 experiments done for each type and certain portion of the FCM. The results (t_b or t_e , values measured for identical samples) which differ from the average value for more than 5% were excluded from the consideration.

Systematic errors for main parameters were: droplet size (R_d) – $7 \cdot 10^{-6}$ m, droplet velocity (U_d) – 3.4%, times t_e and t_b – 0.5 s, volume V_e – $5 \cdot 10^{-4}$ l. The random errors of the temperature (T_f) measurements were less than 30 K.

3 Results and discussion

The table 1 shows the dependencies of the thermal decomposition suppression time on FCM portion diameter. The times of the total parching of the FCM sample without fire extinction efforts are presented too.

Table 1. The dependencies of the FCM parching time (t_b) and thermal decomposition suppression time (t_e) on the FCM portion diameter (for fixed portion height $h_f \approx 40$ mm).

d_f , m	birch leaves		spruce needles		aspen branches		mixed FCM	
	t_b	t_e	t_b	t_e	t_b	t_e	t_b	t_e
0.02	103.3	33.5	159.7	6.2	382.4	14.2	134.7	17.0
0.04	147.7	72.0	192.2	10.9	407.3	24.3	194.4	36.9
0.06	189.6	109.1	228.9	19.3	463.2	41.5	258.3	57.5
0.08	229.0	144.8	267.0	34.3	550.1	71.1	326.4	78.6
0.1	266.1	179.0	315.2	60.7	668.1	121.6	398.7	100.4
0.12	300.8	211.80	364.7	107.6	817.2	208.2	475.2	122.6
0.14	333.0	243.2	418.4	190.7	997.3	356.2	555.9	145.5

It is shown that the FCM total parching times t_b are much longer than fire extinction times t_e . It means that water aerosol can be effective tool for forest fire suppression.

The remarkable parameter of the fire extinction efficiency is the water consumption for the chosen method. Table 2 demonstrate the dependence of the water amount used for the model fire site extinguishing on the FCM portion volume V_f . These dependencies were obtained by generalization of the experimental data when FCM portion height (h_f) was in range from 40 mm to 100 mm and the portion diameter d_f from 20 mm to 80 mm, that is for ranges when the irrigation density ξ_f has relatively low influence onto the experimental results. The thermal effect of the burning layer has the definitive influence at this case.

Table 2. The dependence of water consumption (V_w , l) on the FCM portion volume (V_f , m³).

V_f , m ³	birch leaves	spruce needles	aspen branches	mixed FCM
0.0002	0.004	0.003	0.005	0.01
0.0004	0.007	0.005	0.011	0.015
0.0006	0.014	0.013	0.02	0.019
0.0008	0.023	0.021	0.034	0.025
0.001	0.036	0.035	0.05	0.03

It was shown that the growth of the FCM layer thickness h_f from 40 mm to 100 mm leads to growth of the V_e for not more than 50–60 %. The growth of the model fire site diameter d_f from 20 mm to 60 mm leads to essential growth (for 3–4 times) of the V_w . The analysis of table 2 allows to estimate the water volumes needed for effective suppression of the FCM decomposition for surfaces which are much higher than were used in our experiments. It was shown that 1 m² of the spruce needles needs in 0.7 l of water aerosol, the birch leaves needs – 0.85 l/m² and mixed FCM needs 0.9 l/ m². Together with this the traditional techniques needs from 2–3 l/ m² to 8–10 l/ m².

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