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Experimental Study of the Influence of Ignition Source Position on the Parameters of Peat Fire Propagation

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Abstract. The penetration of smoldering combustion into the peat layer was experimentally studied taking into account a different botanical peat composition typical in the Tomsk region of Russia. The laboratory tests allowed us to obtain and analyze the temperature of the peat samples versus time, and also to estimate the velocity of the smoldering combustion in the horizontal and vertical directions. The results showed the faster penetration of smoldering combustion into the grass-sphagnum peat compared with the pine-cotton peat. The botanical composition and the flow of oxidizers in the combustion zone have a significant effect on the smoldering combustion, especially on the penetration of smoldering front into the peat layer. The chaotic distribution of the fuel particles contributes to the propagation of smoldering combustion both in the horizontal and vertical direction and influences on the spread of the smoldering front.

INTRODUCTION

A number of foreign works is devoted to the physical studies concerning the smoldering process of peat, in particular, the authors of the works [1-8] investigate the dynamics of smoldering for various types of peat, the probability of ignition, the properties of aerosols released during the combustion of peat, as well as a number of works related to the mathematical modeling of peat smoldering [9-11].

In our country, this problem has been also intensively studied. It is necessary to emphasize the works [12, 13] which analyze the thermal and physical peat properties (thermal conductivity, heat capacity, combustion heat of a substance) determining the velocity of the smoldering front and the heat exchange of fuels with the environment. The experimental studies concerning the propagation of peat fires are considered in [14-18]. As a result, the initial temperature of the ignition source was obtained versus the heat exchange with the ambient air and the moisture content of peat, and the modes of ignition and smoldering of peat were investigated in the air flow and in the absence of the air flow in the laboratory conditions.

At present the investigation of peat fires is connected with certain difficulties due to the inhomogeneous structure and the different chemical and botanical composition of peat that is a complicated subject for the study. The increased fire hazard of peat is caused by its porous structure and low density, which results in the fact that the combustion process in peat deposits becomes buried without air. A promising method for studying the propagation of peat fires is the thermography method. There are the experimental works which estimate the characteristics of a horizontal peat fire front [8, 19], as well as the depth of the peat combustion front [20] with the use of this method.

These results can be used in the mathematical modeling of the peat ignition, but there are same difficulties connected with the use of this information as practical recommendations, since these results are mostly obtained using the reference ignition source (steel sample, thin spiral, etc.) to initiate the ignition of the peat sample. The experimental studies concerning the transition of the smoldering front during the surface fire consisting of fuels (pine needles, litter, etc.) to the peat deposits will allow us to verify the available mathematical models of the peat smoldering and give practical recommendations for localization and extinguishing of peat fires.

In addition, there is a need in the more detailed analysis concerning the effect of the botanical peat composition on the characteristics of ignition and smoldering.

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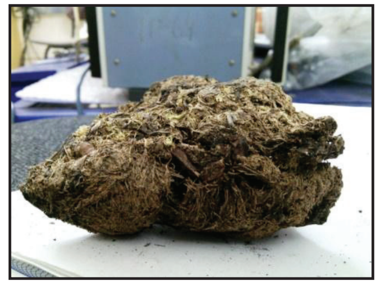
This paper provides the results of the laboratory experiments demonstrating the ignition characteristics of pine-cotton and grass-sphagnum peat versus the moisture content and the botanical composition, as well as the propagation of the smoldering front in peat layer for different location of the ignition source.

EXPERIMENTAL PROCEDURE

The samples of pine-cotton and grass-sphagnum peat are analyzed since these types of peat are the most widespread in the Tomsk region of Russia (Fig. 1) [21].

(a)



(b)

FIGURE 1. Samples under study: (a) pine-cotton sample, (b) grass-sphagnum sample

Table 1 provides the botanical composition for certain types of peat. The botanical composition was determined using a microscope and the quantitative percentage ratio for the residues of peat-forming plants composing the vegetable fiber in the sample. The method used for finding the decomposition degree of the peat samples was to determine the percentage ratio between the area occupied by the unstructured part and the entire area occupied by the unstructured part and plant residues which represented the fibers with a preserved cellular structure.

TABLE 1. Botanical composition and decomposition degree of peat samples

Types of Peat	Botanical Composition	Quantitative Composition, %	Degree of Decomposition, %	Classification by Properties and Role in Occurrence and Spread* of Fire
Pine-Cotton	Eriophorum (cottongrass)	50	20	2
	Bark, pine wood	35		1
	Ericaceous (heath) dwarfshrubs	unit		3
	Sphagnum magellanicum	5		1
	Sphagnum fallax	unit		1
	Sphagnum angustifolium	5		1
	Sphagnum balticum	5		1
Grass-Sphagnum	Sphagnum magellanicum	50	25	1
	Sphagnum cyclophyllum	5		1
	Sphagnum mendocinum	5		1
	Sphagnum balticum	5		1
	Scheuchzeria	15		1
	Menyanthes	10		1
	Carexlimosa	10		2
	Carexrostrata (bottle sedge)	unit		2
	Carexlasiocarpa	unit		2
	Ericaceae (heath) dwarf shrubs	unit		3

(Note: 1 – combustion conductors; 2 – combustion-sustaining materials; 3 – materials retarding the combustion propagation).

The peat-forming components of fuel bed differ in properties, contribute to the initiation and propagation of fires and are represented by three classes: combustion conductors, combustion-sustaining materials, and materials retarding the combustion propagation.

The penetration of the fire front, modeled by the forest fuels (needle litter) and located on the peat surface, into the peat was studied using a test complex [18] according to the schemes represented in Fig. 2. Since, in the nature the underlying surface is located over the peat [18], the two different scenarios are modeled for the surface fire: 1) (Fig. 2, a) the fire front, modeled by forest fuels (FF), moves to the peat deposits located under the soil; 2 (Fig. 2, b) the ignition of the FF layer and the fire development take place directly over the peat deposits.

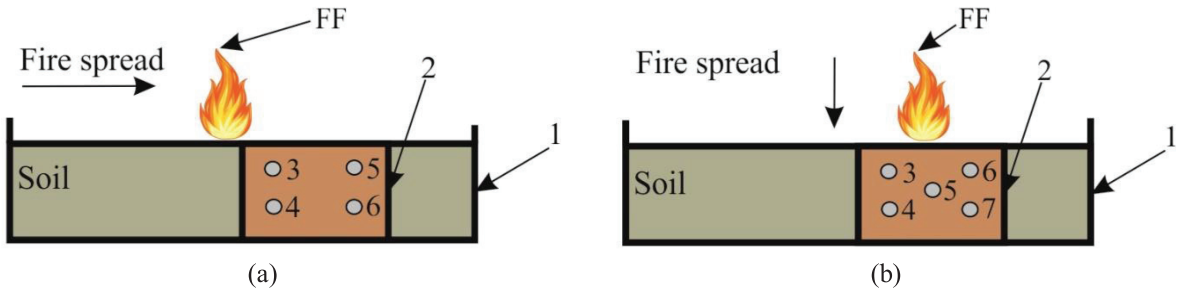


FIGURE 2. Schematic view of the experiment: 1 – metal box-testing area; 2 – peat sample; 3–7 – thermocouples in the peat sample. The distance between the thermocouples is $1 \cdot 10^{-2}$ m

The cubic peat sample with a size of (0.1×0.08×0.06) m^3 was placed into the box filled with soil. To control the movement of the smoldering front and estimate the velocity, the thermocouples (K-type, the junction diameter is 200 microns) were installed in the sample. The upper part of the peat sample was on the surface, and the rest of the peat sample was in the soil layer. Then the forest fuel was placed to imitate a low intensity surface fire, as shown in Fig. 2.

To estimate the velocity of the peat smoldering front from the bottom to the surface, the experiment is conducted as follows (Fig. 3).

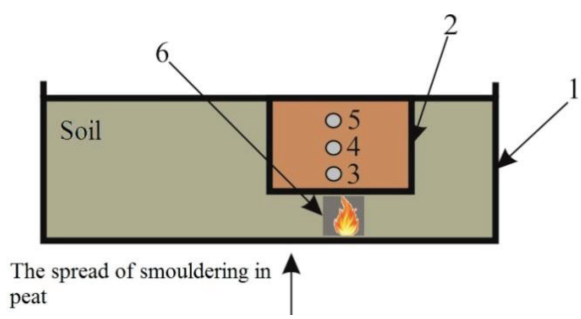


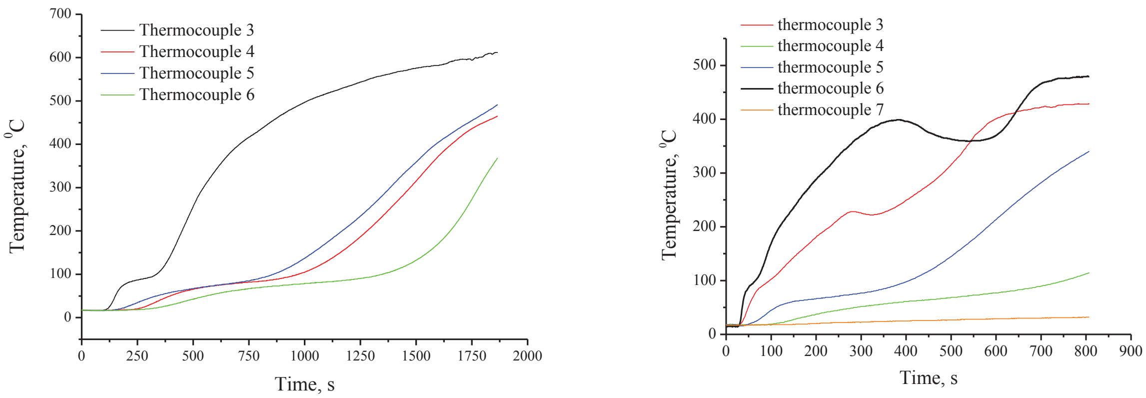
FIGURE 3. Schematic view of the experiment: 1 – metal box-testing area; 2 – peat sample; 3–5 – thermocouples in the peat sample; 6 – igniter (glowing spiral). The distance between the thermocouples is $1 \cdot 10^{-2}$ m

The glowing spiral (the contact surface with a sample is 100 mm^2) was used as a source of ignition and placed directly under the sample in the central part. The spiral was made of a nichrome wire. The resistance was 23 Ohms. The remote ignition was carried out by applying the voltage to the spiral through the power supply. The spiral was heated by a controlled current source up to a temperature of 700 ÷ 1300 K, since this temperature range corresponded to the real fire hazard sources except lightning. The exposure time was chosen based on the experiments and was equal to 20 sec. This experiment allowed the velocity of the smoldering front to be estimated in the vertical direction from the bottom part that was in the soil to the surface.

Before conducting each experiment, the moisture content of the sample, which is described by the percentage equivalent of the ratio of the weight of peat to the weight of the dry basis, was controlled by the moisture analyzer A&D MX-50 with an accuracy of 0.01%. In the experiment the moisture content of the peat was W=1.7%, and the moisture content of FF was W=5.5–5.7%. The air temperature was 290 K, the peat mass was varied within 25 g–27.5 g, and the mass of the FF layer was constant (20 g).

RESULTS AND DISCUSSION

Fig. 4 shows the temperature versus time, when the front of the surface fire penetrates into the peat located in the soil (Fig. 2a) and, in the case, when the fire is initiated directly over the peat in the soil (Fig. 2b). The numbering of the curves in graphs corresponds to the numbering of the thermocouples in Fig. 2.



(a) (b)

FIGURE 4. Temperature versus time in the peat layer for different schemes (a –according to the scheme 2a; b – according to the scheme 2b)

Fig. 5 demonstrates the temperature versus time according to the scheme in Fig. 3.

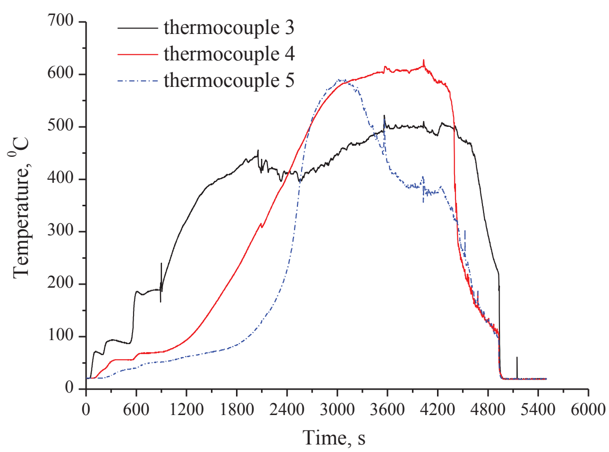


FIGURE 5. Temperature versus time in the peat layer for scheme 3

The stable ignition of the peat samples is observed for the selected parameters of the experiment, which is first recorded by the thermocouple located directly at the surface adjacent to a center of smoldering and reaching the values of 620^0C–630^0C (curve 3 in Fig. 4,a). In a case, when the center of smoldering develops directly over the layer of peat (Fig. 2b), the penetration of smoldering into the peat was first recorded by the thermocouples 3 and 6 located at the FF-peat boundary. The penetration of smoldering into the layer develops nonuniformly, which is also explained by the influence of the botanical composition and the chaotic distribution of the fuel particles in peat.

The analysis of the temperature versus time in Fig. 5, according to the ignition scheme in Fig. 3, allowed us to estimate the penetration of smoldering into the peat deposits from the bottom to the surface.

To evaluate the rate of smoldering combustion in peat samples we conducted three iteration of the experiment, and then, knowing the distance between the thermocouples and the time during which the smoldering front passed this distance (according to the thermocouple), we calculated this parameter. The velocities of peat smoldering exposed to the surface fire and glowing spiral are obtained in the horizontal and vertical directions and given in Table 2.

TABLE 2. Rate of smoldering combustion in peat samples

Types of Peat	MC, %	v, mm/min, in Horizontal Direction	v, mm/min, in Vertical Direction (Towards to Front of Smoldering) Top Down Scheme	v, mm/min, in Vertical Direction (Towards to Front of Smoldering) Down Up Scheme (Using Spiral Igniter)	v, mm/min, in Diagonal Direction
Pine-Cotton top grass	1,7	1,5	1,1	0,39	1,2
Grass-Sphagnum transition	1,7	1,7	1,4	0,44	1,55

It should be noted that the velocity values of the smoldering front propagation in the horizontal direction for the peat under study are in good agreements with the work [13]. The analysis of the values in Table 1 shows that in the case when the ignition is initiated at the upper part of peat, the velocity of the smoldering front in the vertical and diagonal direction is 20% and 22% higher for the grass-sphagnum peat (the combustion conductors are over 70%) compared with the pine-cotton peat. However, modeling of combustion at the bottom part of the peat layer located in the soil (scheme in Fig. 3), allowed us to find that the velocities of the smoldering front in the vertical direction were similar for both types of peat, which is likely to be connected with the limited flow of the oxidizer influencing on the kinetics of the process depending on the depth of peat.

CONCLUSION

The laboratory tests allowed us to obtain and analyze the temperature of the peat samples versus time, and also to estimate the velocity of the smoldering front in the horizontal and vertical directions. The results showed the faster penetration of smoldering combustion into the grass-sphagnum peat compared with the pine-cotton peat. Thus, it can be supposed that the botanical composition and the flow of the oxidizer in the combustion zone significantly influence on the process of smoldering, especially on the penetration of smoldering front into the peat layer. The chaotic distribution of the fuel particles contributes to the propagation of smoldering combustion both in the horizontal and vertical direction and influences on the spread of the smoldering front.

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