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Experimental research of penetration hearth of burning in the peat layer.

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Abstract
The present paper considers, on the basis of the available data and experimental studies, a variant of deepening of the combustion site with account for the botanical composition. After analyzing the thermocouple data, the experiment have shown that there is a steady transition of combustion from a ground forest fire to the deep layer of peat at a low humidity content and sufficient stock of forest fuel.
The presence of combustion conductors and their chaotic arrangement promote combustion propagation in both the horizontal and the vertical planes.

Keywords*: combustion process, peat, botanical composition, combustion conductors.*

1. Introduction

According to different estimates, the world′s deposit of peat varies from 250 to 500 billion tons (counting moisture content). Peat is widely used in various branches of national economy, in agriculture, medicine, biology, power engineering, etc. Peat is valuable due to the fact that its deposits can regenerate. So, in the world up to 3 billion square meters of peat deposits are formed yearly, which is about 120 times more than used. Peat is characterized by a high natural moisture content of up to 96%, and its porosity amounts to 96% with an average diameter of water-conducting pores of the order of 8.2 μm (Grishin *et al.* 2013).
It should be noted that in determining the kind of peat the most important index is also the degree of decomposition (Nikitin *et al.* 1986). Since peat is an organic compound, under certain conditions its combustion takes place. Peat combustion under natural conditions depends on a complex connected with climatic, meteorological, and topographical factors. This dependence shows up most clearly in a prolonged droughty period when it is necessary to take into account the solar radiation intensity, the air temperature, the time of the day, the ground water level, and many other factors (Belozerov 2010). Peat ignition sources may be different: the sparks from the wires, electrical sparks produced during short-circuit current-carrying wires and cables to the units, careless use of fire, the heat of the sun. Ignition of peat may be due to one of many different causes: sparks from wires, electric sparks produced by short circuit of current-carrying wires and cables to assemblies, careless use of fi re, and the heat of sunbeams. Most often peat beds catch fire from ground forest fires. Three stages of development of a peat fire are distinguished. The first stage has a small area of the site and a low temperature in the combustion zone. It has been established that in the first 1.5–2 hours a peat layer of thickness $(2-4)\cdot 10^{-2}$ m burns up. The second stage is characterized by an increase in the burning velocity and an increase in the zone temperature. The area of the fire increases to several thousands of square meters, and the combustion becomes stable. Acrid fume propagates for a long distance. The third stage is characterized by a large combustion area, a high temperature in the combustion zone, a high smoke content, and a high fi re propagation velocity (Grishin *et al.* 2013).The fire area is calculated by the formula:

$$F_n = \frac{\Pi \cdot V_n^2 \cdot t_p^2 \alpha}{360} = 0{,}00873 V_n^2 \cdot t_p^2 \alpha$$

The approximate change with time in fire areas at various wind velocities is presented in paper (Grishin *et al.* 2013).
It should be noted that the burning of peat in natural conditions is carried out with an excess moisture content and lack of oxidant decay mode (Grishin 1986). Combustion has a diffusive character as limited intake of oxidant environment.
It should be noted that all the well-known works do not consider a botanical composition of peat to be a factor for penetration of the combustion front in the mass of peat. The influence of the botanical composition on ignition of peat is given in the work (Grishin *et al.* 2006) that provides the results of experiments for determination of the minimum ignition energy, and in the work (Loboda 2012) that provides the results of experimental studies to determine the depth of the combustion front in the peat layer. The samples represented four types of peat with different characteristics (botanical composition, density, humidity content and degree of decomposition). We have found that the depth of the combustion front in peat is varied in the range of 10-28 mm, depends on the type of peat, the degree of decomposition, the density and is weakly dependent on the changes of humidity content in the range from 2.6 to 17.3% and does not depend on the size of the sample in the range from $0.3 \times 0.3 \times 0.3$ to $0.35 \times 0.15 \times 0.15$ m.
In this work we suggest an explanation of self-penetration of the combustion front, taking into account the botanical composition of peat. Peat is characterized by the bimodal particle size distribution connected, on the one hand, with the presence of coarse particles of plants and, on the other hand, with a finely-dispersed fraction consisting of the decomposition products. Coarsely dispersed residues, forming a carcass grid or representing a «filler», have an average particle size from 0.1 to 4.5 mm (Churaev 1961).

2. Technique of the experiment

We assume that peat fire occurs due to the ground forest fire initiated by needle and leaf litter. In the work, the mechanism for penetration of combustion is investigated and evaluated in the peat layer of a different botanical composition.
When the ignition takes place on the surface, combustion (smouldering) will be propagated in the mass of peat. In order to check this assumption, in the laboratory we conducted a series of experiments for modeling the ignition of peat from ground forest fire (Figure 1) using a test complex (Grishin *et al.* 2009).

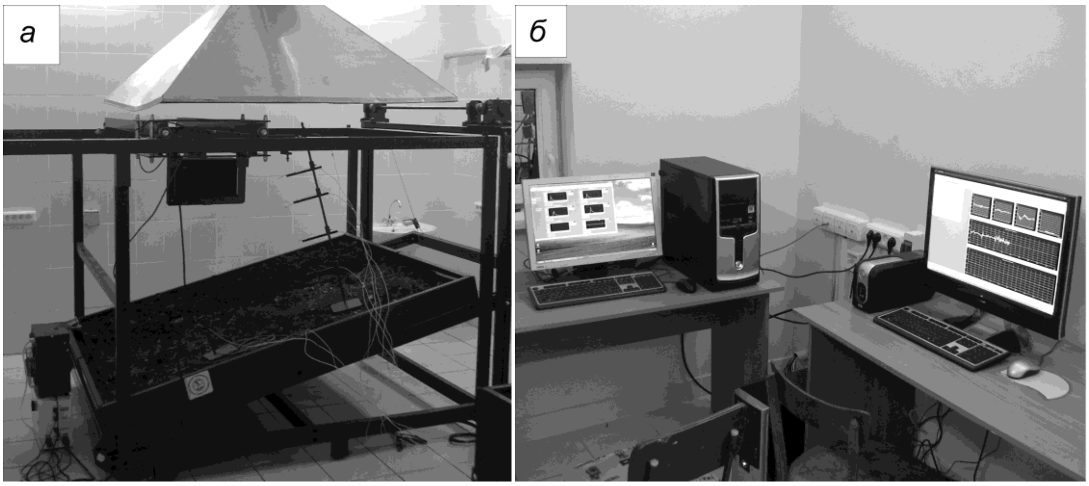

Figure 1. Facility for physical modeling of ground and steppe fires (a); system of data input and registration (б) (Grishin et al. 2009).

There are a complex of measuring equipment and an automated data acquisition and recording system based on a computer and three five-channel ADCs with chromel-alumel thermocouples. The input data recording program was developed on the basis of the Labview program complex. The humidity content of peat is determined using a humidity analyzer A&D HX-50 with an accuracy up to 0.01%. The weight of the samples was determined using an electronic balance A&D HL-400 with an accuracy of 0.1g. Forest fuels (FF) was ignited using a linear source of ignition in the form of a spiral. Combustion temperature was measured by a thermocouple method using chromel-alumel thermocouples.
The scheme of the experiment is presented in Figure 2. A peat sample (2) with sizes $(0.08 \times 0.065 \times 0.05) \cdot m^3$ is placed on the bottom of the metal box (1). Four thermocouples were set in the peat sample: one in the near-surface layer closer to the FF (3), one on the axis inside the peat layer at a distance of $1 \cdot 10^{-2}\ m$ (4), one on the axis at a distance of $2 \cdot 10^{-2}\ m$ (5), and thermocouple (6) was set below thermocouple (3) at a distance of $1 \cdot 10^{-2}\ m$ from it and at a distance of $2 \cdot 10^{-2}\ m$ from the peat surface adjoining the FF. Ignition was realized by means of a point source.

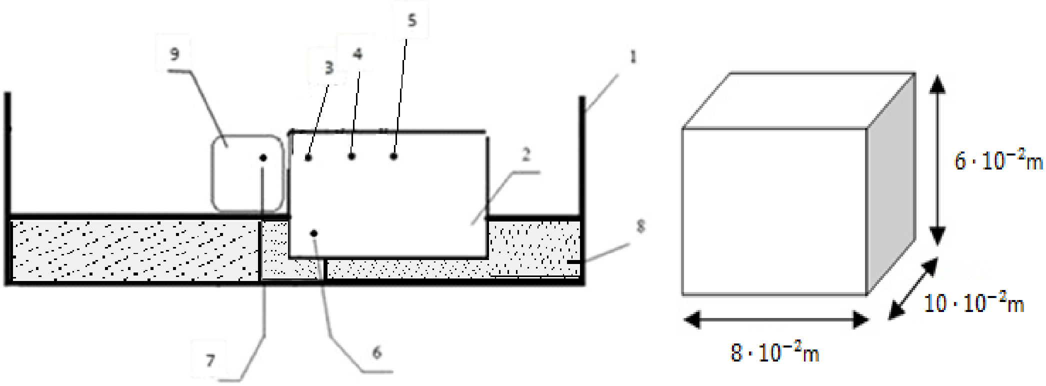

Figure 2. The scheme of the experiment (side view) and dimensions of peat samples (right one). 1 - metal box-testing area; 2 - peat sample; 3,4,5,6 - thermocouple in the peat sample, 7 – thermocouple in the FF layer; 8 - ground substrate; 9 - FF layer.

Since the underlying surface is over peat in the nature, we modeled two variants for the development of underground fire (Figure 3):

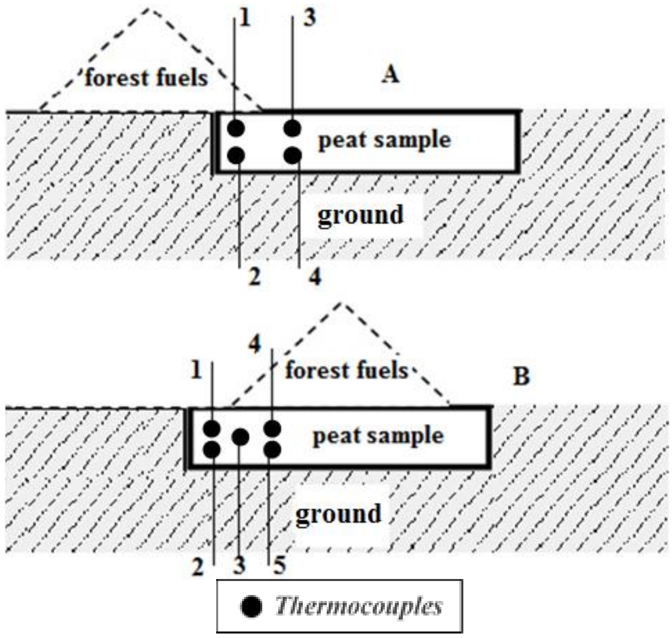

Figure 3. The scheme of experiment: A – Ground forest fire front coming to peat layer, buried in the ground; B - Initiation of ground forest fire occurs directly above the peat, buried in the ground;

The main parameters:
$M_{peat} = 27{,}3\ г$, $M_{FF} = 20\ г$, $W_{peat} = 4{,}7\ \%$, $W_{FF} = 5{,}7\ \%$, $T_{initial} = 17^0 C$.

We studied the samples with a different botanical composition of peat (Grishin *et al.* 2013).

3. Analysis of the structure of peat samples

To analyze the structure of the peat layer, peat samples with a different humidity content were photographed using the microscope. Figure 4 shows the photographs with a vertical section of peat samples (deposit in the settlement of Plotnikovo, Tomsk region) with a magnification of 200 times. Plant residues ***A*** and water-conducting pores ***B*** are clearly observed.

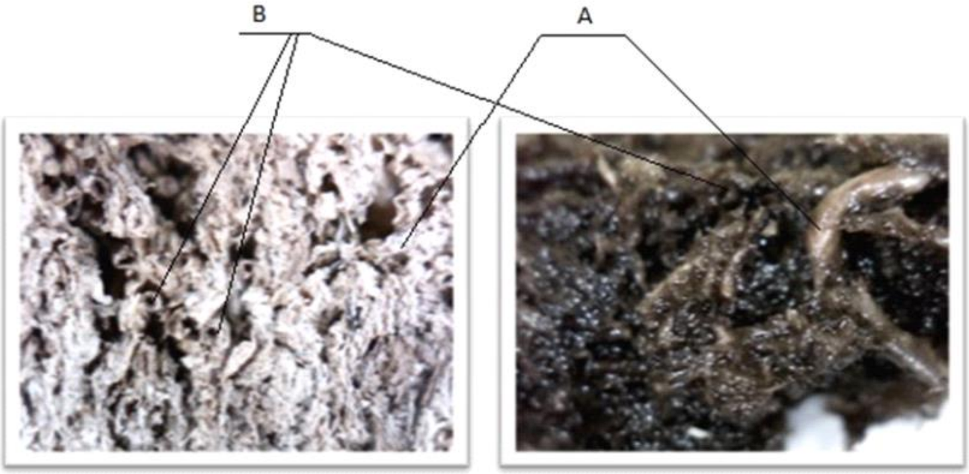

Figure. 4. Vertical slice of peat sample: $W = 4,7$ % (left one) и $W = 57,7$ % (right one).

Taking into account the properties and the role of initiation and propagation of fires, the components of the ground layer forming peat are unequal and divided into three classes: conductors of combustion, materials supporting combustion and retarding combustion propagation (Grishin *et al.* 2013).

The conductors include the materials that quickly become wet and then quickly become dry. Therefore, they are the materials that ignite very fast and provide a continuous propagation of flame over the ground cover.

Materials supporting combustion include live plants regulating evaporation, with a constant high humidity (more than 70%) and a small volume weight of the layer. This fact does not allow combustion to propagate spontaneously. They can burn only together with the conductors of combustion, increasing the total intensity of the fire line.

Materials retarding propagation of combustion are the materials which can not burn naturally due to the high humidity. They significantly reduce the total intensity of combustion, since the ignition and combustion requires a large amount of heat.

4. Analysis of experimental data

Figure 5A shows time dependence of the temperature change for the humidity content of the peat $W = 4.7\%$ according to the first scheme of the experiment (Figure 2).

Figure 5B shows time dependences of the temperature change for the humidity content of the peat $W = 57.7\%$ according to the same scheme of the experiment.

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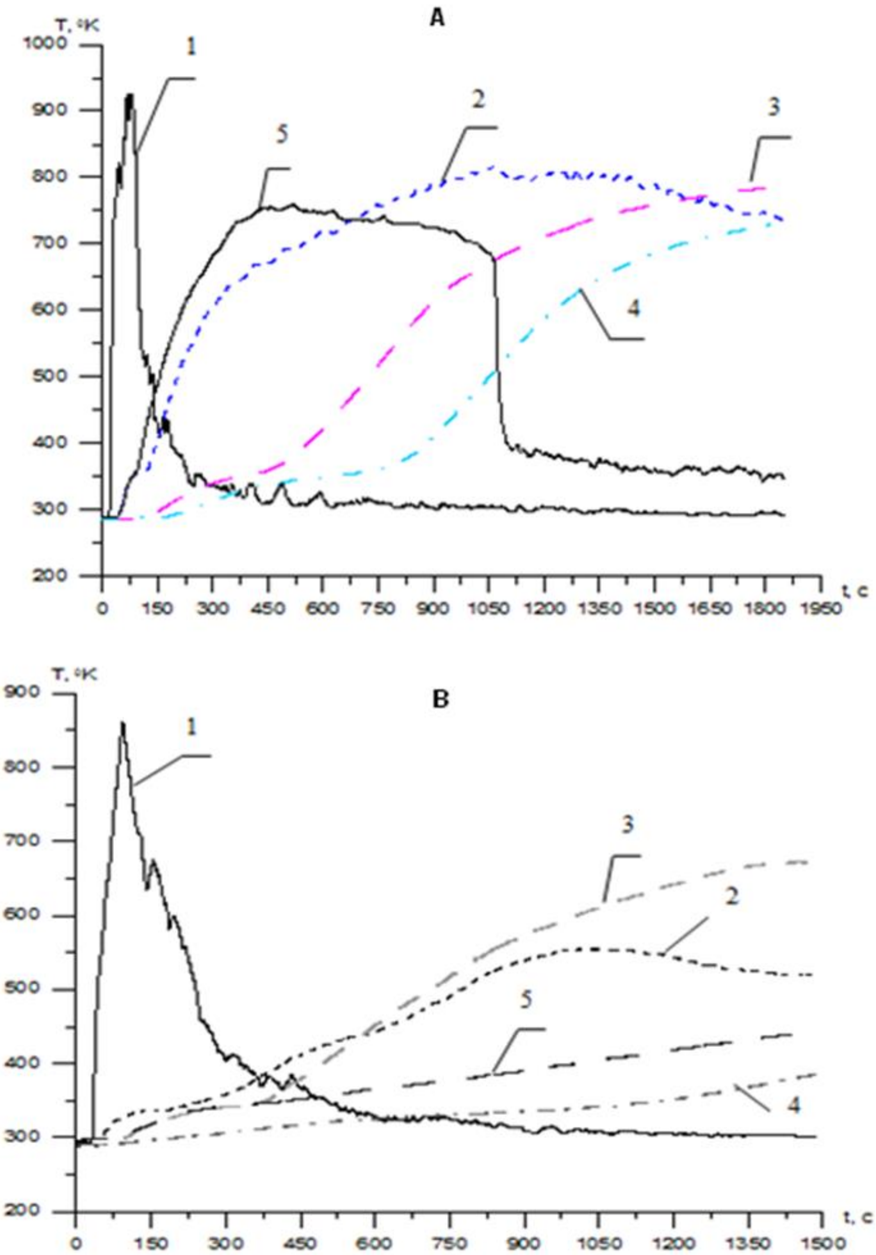

Figure. 5. Time dependences of the temperature change (A-moisture of peat samples $W = 4.7\%$, B-moisture of peat samples $W = 57.7\%$): 1- temperature in the FF layer, 2- temperature change at the boundary between the layer of peat and FF, 3- temperature change on the axis in the layer of peat at the distance of $1 \cdot 10^{-2}$ m from the thermocouple 3 (Figure 3), 4- temperature change on the axis in peat at a distance of $2 \cdot 10^{-2}$m, 5-temperature change in the lower part of peat layer.

Thus, combustion (smouldering) propagates in the mass of the peat sample (2) faster than in the horizontal direction. The rate of the fire front is approximately 0.19 mm/s at a distance of $1{\cdot}10^{-2}$ m between the thermocouples.

Analyzing the plots, it is seen that the transition of combustion from FF to peat is slower for the more wetted sample of torus. In general, combustion has a focal character, which is consistent with the different works (Reardon 2007; Ohlemiller 2002). Thus, combustion (smouldering) propagates in the mass of the peat sample (2) faster than in the horizontal direction. The rate of the fire front is approximately 0.19 mm/s at a distance of $1{\cdot}10^{-2}$ m between the thermocouples (Grishin *et al*. 2013).

Time dependences of the temperature change in accordance with second scheme of experiments (Figure 3A) are shown on Figure 6.
Figure 7 shown the time dependences of the temperature change for the case where the seat of the fire was initiated immediately above peat layer (Figure 3B).

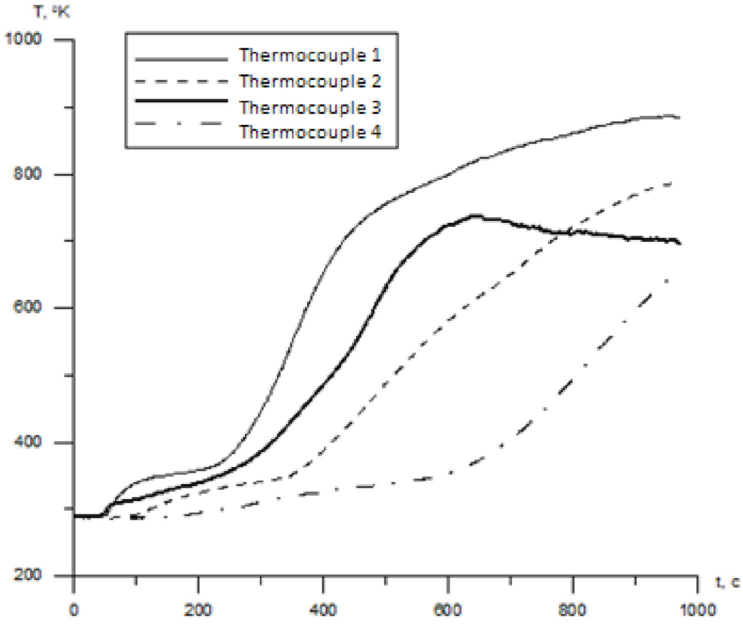

Figure 6. Time dependences of the temperature change. The numbering of the curves corresponds to the numbering of thermocouples in Figure 3A.

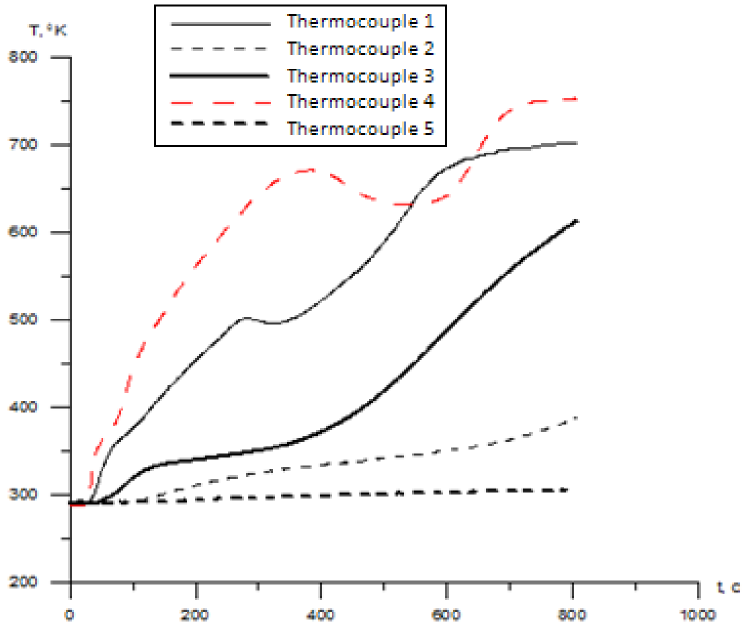

Figure 7. Time dependences of the temperature change. The numbering of the curves corresponds to the numbering of thermocouples in Figure 3B.

After analyzing the thermocouple data, the experiment have shown that there is a steady transition of combustion from a ground forest fire to the deep layer of peat at a low humidity content and sufficient stock of forest fuel. The mechanism of penetration is mainly dependent on the botanical composition of peat. The presence of combustion conductors and their chaotic arrangement promote combustion propagation in both the horizontal and the vertical planes.

Complete understanding of the mechanism of penetration of combustion in peat layer requires additional investigations involving IR-methods, as well as mathematical modeling and comparison with the existing data.

5. Results

1. The experiments to study the deep of combustion in the peat layer from the front of a ground forest fire have been prepared and conducted.
2. The rate of peat burning has a value of about 0.19 mm/s.
3. The combustion has a site character, which agrees with the data of (Reardon 2007; Ohlemiller 2002).
4. Analysis of the structure of peat samples has been conducted. It has been noted that the characteristic of peat structure is the presence of burning conductors and water conveyance pores. The penetration of combustion may occurs on them.

6. Acknowledgements

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