# EXPERIMENTAL INVESTIGATION OF PEAT IGNITION AND COMBUSTION REGIMES

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*A new (flame) regime of peat combustion in an air flow has been experimentally investigated. It has been established that the rate of combustion of a peat depends on its density and moisture content, which makes it possible to refine the mathematical model of a peat fire. The mechanism of catalytic peat combustion was determined.*

**Introduction.** It is known that the peat fires that occurred in the Moscow region in September 2005 had negative consequences (the work of peat-processing plants was terminated, fires arose in settlements and villages of the Moscow region, and the territory of Moscow and the Moscow region was screened with smoke). The regimes of peat ignition and combustion under conditions close to the conditions of a natural peat fire were investigated in [1], and the kinetic characteristics of a low-temperature peat combustion were determined in [2]. On the basis of the experimental data obtained in [1, 2], a general mathematical model of a peat fire was constructed in [3], and this model was verified in [4]. However, at present there is very little data on the energy, regimes, and rate of combustion of peats of different type. Therefore, the aim of the present work is to investigate the regimes of peat ignition as well as to determine the minimum energy of this ignition and the dependence of the rate of combustion of peats having different botanical compositions on their density, moisture content, ash content, and degree of decomposition under laboratory conditions.

**Experimental Procedure.** The combustion of a peat was experimentally investigated on a setup, the diagram of which is presented in Fig. 1. Cubic peat samples 1 were placed on a concrete base 2. The side surfaces of the samples were surrounded by brickwork 3, and the upper part of their surface 4 remained open. The peat samples were ignited at the center of their open surface (at the point 0) with the use of a standard fire source [5]. The rate of combustion, the position of the fire front, and the temperature of the peat were determined with the use of chromel-alumel thermocouples having a junction of diameter $2 \cdot 10^{-4}$ m. The themocouples were positioned in the mutually perpendicular three directions $x$, $y$, and $z$, originating at the point 0 positioned within the site of ignition 4. Moreover, the position of the fire front was photographed. In some cases, for simulation of the wind action, the burning peat samples were subjected to a uniform forward air flow, the undisturbed velocity of which $\mathbf{v}_e$ was parallel to their open surface 4 (see 5 in Fig. 1). This flow was produced with the use of a subsonic MT-324 wind tunnel. Samples of a valley peat, having a high degree of decomposition and a high ash content, were taken from different depths of occurrence in the Timiryaz'evsk and Bakcharsk Forestries of the Tomsk region. Prior to the experiments, the moisture content $W$, the density $\rho$, the ash content $Z$, and the degree of decomposition $\varphi$ of the peat were determined.

The peat was ignited with the use of a standard ignition source [5]. The heat energy released from the surface of this source in the period from the instant it contacted with the peat surface to the instant a combustion began $t_c$ was considered as the minimum combustion energy $Q$.

The density of a heat flow $q$ was measured experimentally with the use of a temperature-sensitive element [5], and the rate of propagation of the fire front was determined as $v_1 = S_1/t_1$. To eliminate the systematic error arising in the case where the structure of a peat sample is determined by its temperature measured by the contact method, we used a single thermocouple in an electrically and thermally isolated jacket. This thermocouple was installed at the point with coordinates $x_1$, $y_1$, and $z_1$. After the fire front reached this point, the experiment was stopped and another peat

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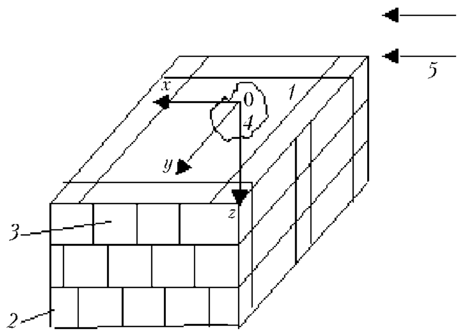


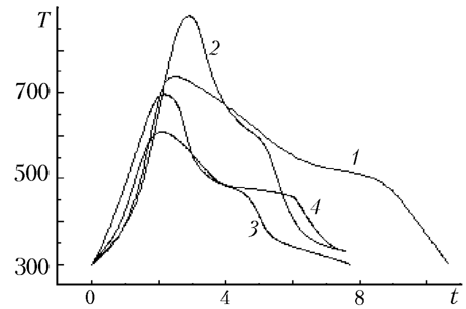


Fig. 1. Axes of the Cartesian coordinate system and scheme of an experiment.

Fig. 2. Change in the temperature of a peat with time: 1) $x$ = 0.04, $y$ = 0, $z$ = 0; 2) 0.02, 0, 0; 3) 0.04, 0, 0.03; 4) 0.04; 0, 0.06. $T$, K; $t$, min.

TABLE 1. Characteristic of the Botanical Composition and the Degree of Decomposition of Peat Samples Taken from the "Bakcharskoe" Bog

| Number of sample | Depth from which a peat was taken, m | Composition of vegetable remainders | Content of remainders, % | Degree of decomposition, % | Type of peat |
|---|---|---|---|---|---|
| 1 | 0.05—0.15 | Pine crust and wood<br>Jointed sedge<br>Tussok sedge<br>Hairlike sedge<br>Broad-like sedge | 65<br>20<br>3<br>1<br>Unit | 35—40 | Valley wood peat |
| 2 | 0.40—0.52 | Horse-tail<br>Sphagnum Magellan<br>Pine crust and wood<br>Birch crust and wood<br>Dwarf birch crust and wood<br>Cotton grass | 10<br>1<br>30<br>5<br>10<br>30 | 50 | Transient wood-cotton-grass peat |
| 3 | 0.20—0.30 | Sphagnum brown<br>Rootlets of heather bushes<br>Peat crust | 90<br>10<br>1 | 5 | Fuscous peat |

TABLE 2. Rate of Combustion of a Peat (numbers of samples correspond to the botanical composition of the peat samples in Table 1)

| Number of experiment | Number of sample | $v_e$, m/sec | $v_1$, m/sec | $v_2$, m/sec | Note |
|---|---|---|---|---|---|
| 1 | 1 | 0 | $9.69 \cdot 10^{-6}$ | $9.41 \cdot 10^{-6}$ | Catalytic combustion |
| 2 | 2 | 2.5 | $5.38 \cdot 10^{-5}$ | $15 \cdot 10^{-5}$ | Flame combustion |
| 3 | 3 | 3.5 | $4.77 \cdot 10^{-5}$ | $4.88 \cdot 10^{-5}$ | Catalytic combustion in a flow |

sample was investigated with the use of the thermocouple positioned at the point with coordinates $x_2$, $y_2$, $z_2$, and so on. The summarized errors in the temperature and density of the heat flow were equal to $\delta T < 4.6\%$ and $\delta q < 9.1\%$.

**Characteristics of Peat Samples and Results of Measurements of Their Temperature.** The botanical composition and the degree of decomposition of the peat samples being investigated are presented in Table 1.

Figure 2 shows typical oscillograms of the temperature of a peat measured at different points of it. As the fire front is approached, the temperature of the peat increases and reaches maximum values $T_{max}$ = (683–873) K in the combustion zone, which is consistent with the results of the natural experiment [1].

**Rates and Regimes of Peat Combustion.** Table 2 presents the projections of the peat-combustion rates $v_1$ and $v_2$ on the axes positioned along the coordinates $0x$ and $0z$. It was established that, at a certain velocity of the laminar air flow $v_c$, there arises a flame regime of peat combustion (Table 2, experiment 2, and Fig. 3a) in the narrow

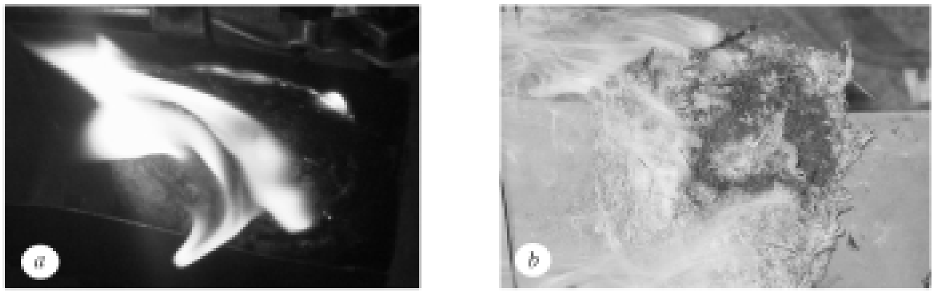

Fig. 3. Flame combustion (a) and catalytic combustion (b) of a peat.

range of external air-flow velocities 2.5 m/sec $\le v_e < 30$ m/sec. Moreover, a catalytic combustion, investigated in [1], was detected (see Fig. 3). The rate of flame combustion on the surface of the peat samples increased and the rate of this combustion in the bulk of the samples decreased, which is explained by the inflow of the oxidizer, provided by the wind, and the change in the kinetics of the process. The rate of surface-flame combustion in an air flow is higher than the rate of catalytic combustion because of the intensification of the diffusion of the oxidizer flows deep inside the peat samples (Table 2).

As visual observations have shown, under the natural convection conditions, a catalytic peat combustion (the smoldering regime) is realized. After a peat is ignited, the fire front propagates to its deeper layers, which is apparently due to the difference in density between the peat layers and the different conditions of filtration in them and interaction between the combustible and oxidizer. The combustion front is very inhomogeneous, the combustion products of the peat have a grey-white color, and the process of combustion occurs with the formation of smoke. The combustion temperature of the peat samples being considered was equal to $T_c$ = (618–873) K, which is consistent with the data of [1], where it was established that $T_c$ = (623–673) K. The temperature of combustion in a layer located deep in a peat sample was higher than the temperature of combustion at its surface, which is consistent with the data of [5]. The rate of combustion of the peat samples was dependent on their moisture content, botanical composition, and density. This dependence was nonmonotonic.

It was established that the combustion rate of a peat is maximum when it has an optimum density $\rho = \rho_*$. The rate of combustion of a low-density peat is low because of the deficiency of the combustible and the low heat-conductivity coefficient of the peat. In a peat having a high density $\rho$, the filtration processes in the pores, associated with the inflow of the oxidizer and the removal of the combustion products, are retarded.

In the case where the moisture content of a peat reaches $W = 0.15$, the rate of its combustion increases by 30%, which can be explained by the increase in the effective heat conduction by analogy with the influence of a small moisture content on the minimum combustion energy. However, a further increase in $W$ leads to a sharp decreases in the rate of combustion, which is explained by the expenditure of heat for the moisture evaporation.

The rate of combustion of a peat at a depth $z = 2 \cdot 10^{-2}$ m was equal to the combustion rate at its surface. The rate of peat combustion at a depth $z = 8 \cdot 10^{-2}$ m was 20% lower than that at the surface, which is explained by the increase in the peat density $\rho$, preventing the penetration of the oxidizer to the combustible material through the peat pores.

The combustion of a peat in the absence of wind can be considered as a smoldering, in which the combustion rate is determined by the filtration-diffusion processes of supply of an oxidizer (air) through the peat pores to the dry combustible. The above-described mechanism of combustion of a peat is supported by the nonmonotonic dependence of the rate of combustion of the peat samples being investigated on their density as well as by the results of special experiments on the ignition of a peat in the inert atmosphere. Peat samples were placed in a vessel filled with an inert gas — argon. A standard ignition source was positioned on the surface of a sample; in this case, peat ignition did not occur.

The data obtained are in good agreement with the data obtained in [1], where, at $W = 0.15$, the rate of combustion of an embankment peat under natural-convection conditions was $v \sim 1$ mm/min; at $W = 0.7$, we obtained $v$ = 0.1 mm/min.

## CONCLUSIONS

1. A new flame regime of peat combustion in an air flow in the narrow range of wind velocities $2.5 \le v_e < 3.0$ m/sec was detected.

2. It was shown that a catalytic diffusion combustion of a peat arises as a result of the penetration of oxygen from the ambient air through the peat pores.

3. It was established experimentally that the rate of combustion of a peat depends on its density and moisture content, which allows one to verify the general mathematical model of a peat fire.

## NOTATION

$m$, mass of a sample, kg; $m_0$, mass of the sample dried at $T$ = 373 K; $m_f$, mass of the burnt sample, kg; $Q$, minimum ignition energy, J; $q$, density of a heat flow, W/m$^2$; $S_1$, distance of propagation of the fire front along the $x$ axis; $t_1$, time of combustion, sec; $t$, time, sec; $T$, temperature, K; $\mathbf{v}_e$, velocity vector of an air flow over the surface of a peat, m/sec; $v_e$, velocity of an air flow over the surface of a peat, m/sec; $v$, velocity of propagation of the fire front, m/sec; $v_1$ and $v_2$, velocities of propagation of combustion of a peat layer along the $x$ and $z$ axes, m/sec; $W = (m - m_0)/m_0$, moisture content of a sample; $x$, $y$, $z$, coordinates of the fixed Cartesian coordinate system with the origin positioned on the open surface of a sample inside a contour bounding the nucleation site of the combustion, m; $Z = m_f/m$, ash content; $\delta T$ and $\delta q$, relative errors in the temperature and density of the heat flow, %; $\rho$, density of the peat, kg/m$^3$; $\varphi$, degree of decomposition of the peat. Subscripts: 0, for the mass of a dried sample; 1 and 2, for the rates of combustion along the $x$ and $z$ axes; *, density of a peat layer at a maximum rate of combustion; e, external (for the velocity of the air flow over a peat sample); c, combustion; f, final (for the mass of the burned remainder).

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