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# EXPERIMENTAL STUDY OF PEAT IGNITION AND COMBUSTION

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*Under laboratory conditions, ignition and combustion of peat specimens with a different botanical composition that were taken from different deposits have been studied. The effect of density, moisture content, and ash content on the minimum energy of ignition and rate of combustion of peat has been determined.*

In order to describe drying and pyrolysis with the aid of the known general mathematical model of peat fires [1, 2], the specific heat, thermal conductivity and thermokinetic constants need to be known. At present, data on these quantities are insufficient; therefore, the propagation of peat fires is modeled mathematically [3, 4] using tentative information on thermophysical and thermokinetic characteristics. Furthermore, up till now the scientific literature has no reliable data on the mechanism of peat ignition and combustion, and this precludes the solution of practical problems of operative prevention and extinguishing of peat fires. The current work aims at an experimental determination of the minimum energy of ignition and rate of combustion of peat specimens according to their botanical composition, density, moisture content, and ash content.

**Methods of Determining the Characteristics of Peat Ignition and Combustion.** Peat is a product of incomplete decomposition of plant materials under the conditions of excess humidity and insufficient aeration [1, 2]. The structure and composition can be modeled by a porous multiphase reactive medium consisting of cellulose, lignin, water in a liquid-droplet state, condensed products of pyrolysis, ash, and a gas phase [1, 2].

As the considered specimens, use was made of peat of lowland type with a different botanical composition, a good degree of decomposition and an increased ash content in the Timiryazev and Bakchar forestries of the Tomsk region from various depths of occurrence.

The standard source of ignition, which models actual sources of ignition of peat (like a burning match, a cigarette, or a small smouldering branch) was a thinly wound spiral made from a nichrome wire with a diameter of $1.5 \cdot 10^{-3}$ m [5]. The outside diameter of the spiral was $1.5 \cdot 10^{-2}$ m, and the electric resistance was 23 Ω. The minimum ignition energy $Q$ was taken to mean the value of the thermal energy released from the surface of the standard source of ignition from the instant of its contact with the peat surface up to the instant of the beginning of combustion $t_c$:

$$Q = J \Delta U \Delta t \, .$$

In experiments, we specified the current $J$ and the voltage drop over the spiral $\Delta U$, and controlled its resistance at a working temperature, the ignition time using an electron-digital timer, and the ash content $Z = m_Z/m$.

Peat combustion was studied on an experimental setup, whose schematic is shown in Fig. 1. The peat specimens of cubic shape 1 were laid on concrete base 2, side surfaces of the specimens were surrounded by brickwork 3, and the upper surface remained open. The peat specimens were ignited in the center of their open surface at the point O with the aid of the standard source. Geometric dimensions of the specimens $l$ were selected proceeding from the condition of smallness of the heat sink through their side surfaces: $a/l >> v$.

During experiments, we controlled the peat temperature $T$ at the points $x$, $y$, and $z$ using a chromel-alumel thermocouple with a junction diameter of $2 \cdot 10^{-4}$ m, the heat-flux density $q$ (by the exponential method using the heat flux transducer), and the rate of propagation of the fire front $v$. In order to eliminate a systematic error linked with

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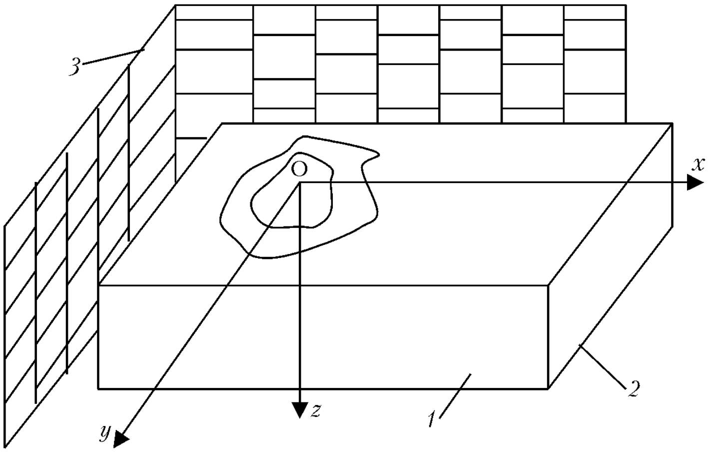

Fig. 1. Schematic of the experimental setup.

TABLE 1. Minimum Energy of Ignition of Peat Specimens Taken from the Timiryazev Forestry

| Specimen number | $W$ | $\rho$, $10^{-3}$ kg/m$^3$ | $\Pi$ | $Z$ | $Q$, J | $\pm\delta Q$, J |
|---|---|---|---|---|---|---|
| 1 | 0 | 0.43 | 0.67 | 0.43 | 162.5 | 31.5 |
| 2 | 0 | 0.48 | 0.63 | 0.41 | 183.0 | 40.1 |
| 3 | 0 | 0.52 | 0.60 | 0.42 | 195.0 | 42.3 |
| 4 | 0 | 0.53 | 0.59 | 0.29 | 243.8 | 48.7 |
| 5 | 0 | 0.38 | 0.71 | 0.12 | 81.25 | 8.2 |
| 6 | 0 | 0.58 | 0.56 | 0.09 | 32.50 | 7.1 |
| 7 | 0 | 0.78 | 0.40 | 0.09 | 81.25 | 9.1 |
| 8 | 0.09 | 0.74 | 0.44 | 0.11 | 81.25 | 7.3 |
| 9 | 0.16 | 0.59 | 0.55 | 0.11 | 16.25 | 4.3 |
| 10 | 0.23 | 0.33 | 0.75 | 0.10 | 16.25 | 4.7 |
| 11 | 0.44 | 0.57 | 0.57 | 0.13 | 162.5 | 41.2 |
| 12 | 0.47 | 0.63 | 0.52 | 0.12 | 243.8 | 51.9 |

TABLE 2. Minimum Energy of Ignition of Peat Specimens Taken from the Bakchar Forestry

| Specimen number | $W$ | $Z$ | $Q$, J | $\rho$, kg/m$^3$ |
|---|---|---|---|---|
| 1 | 3.394 | 0.019 | 2320 | 419.684 |
| 2 | 3.842 | 0.018 | 2645 | 410.573 |
| 3 | 7.910 | 0.008 | 2106 | 672.733 |
| 4 | 5.364 | 0.009 | 3699 | 172.046 |
| 5 | 7.616 | 0.009 | 2700 | 296.114 |
| 6 | 3.245 | 0.022 | 2060 | 351.965 |
| 7 | 3.193 | 0.024 | 1974 | 453.178 |
| 8 | 11.397 | 0.010 | 4590 | 414.364 |

the distortion of the structure of the peat specimens because of the employment of contact methods for determining the temperature, use was made of a single thermocouple in an electrically and thermally insulating case, which was placed at the controlled point with coordinates $x_1$, $y_1$, and $z_1$. Once the fire front reached this point, the experiment was discontinued and another peat specimen was mounted, while the thermocouple was positioned at the point with coordinates $x_2$, $y_2$, $z_2$, etc. The density $\rho$ and the moisture content $W = (m - m_f)/m_f$ of the peat varied. Total errors were no more than $\delta T < 4.6\%$ and $\delta q < 9.1\%$.

TABLE 3. Characteristics of Botanical Composition and Degree of Decomposition of Peat Specimens Sampled on Bakcharovskoe Bog

| Specimen number | Type, kind of peat | Composition of plant residue | Content, % | Depth of sampling of peat specimen, m | Degree of decomposition, % |
|---|---|---|---|---|---|
| 1 | Woody lowland | Bark and wood of pine | 65 | 0.05—0.15 | 35—40 |
| | | Sedge (*Carex appropinquata Shum.*) | 20 | | |
| | | Elata sedge | 3 | | |
| | | Pilose-fruit sedge | 1 | | |
| | | Sedge (*Carex rostrata Stokes*) | 1 | | |
| | | Horsetail | 10 | | |
| | | Magellan sphagnum | 1 | | |
| 2 | Woody lowland | Bark and wood of pine | 30 | 0.15—0.21 | 60 |
| | | Bark of cedar | 5 | | |
| | | Bark and wood of birch | 35 | | |
| | | Bark of dwarf birch | 20 | | |
| | | Sedge (*Carex appropinquata Shum.*) | 5 | | |
| | | Horsetail | 5 | | |
| 3 | Pine-sphagnum upland | Bark and wood of pine | 30 | 0.15—0.25 | 20 |
| | | Rootlets of heath scrubs | 10 | | |
| | | Narrow-leaf sphagnum | 40 | | |
| | | Magellan sphagnum | 10 | | |
| | | Baltic sphagnum | 10 | | |
| 4 | Pine-cotton grass upland | Bark and wood of pine | 35 | 0.25—0.36 | 35—40 |
| | | Rootlets of heath scrubs | 5 | | |
| | | Cotton grass | 55 | | |
| | | Narrow-leaf sphagnum | 5 | | |
| | | Sedge (*Carex rostrata Stokes*) | 1 | | |
| | | Horsetail | 1 | | |
| 5 | Woody-cotton grass transitional | Bark and wood of pine | 30 | 0.40—0.52 | 50 |
| | | Bark and wood of birch | 5 | | |
| | | Bark of dwarf birch | 10 | | |
| | | Cotton grass | 30 | | |
| | | Pilose-fruit sedge | 5 | | |
| | | Sedge (*Carex rostrata Stokes*) | 1 | | |
| | | Horsetail | 5 | | |
| | | Fern | 1 | | |
| | | Magellan sphagnum | 10 | | |
| | | Central sphagnum | 5 | | |
| 6 | Fuscum | Brown sphagnum | 80 | 0—0.10 | 85 |
| | | Rootlets of heath scrubs | 15 | | |
| | | Bark of pine | 5 | | |
| 7 | Fuscum | Brown sphagnum | 90 | 0.20—0.30 | 5 |
| | | Rootlets of heath scrubs | 10 | | |
| | | Bark of pine | 1 | | |
| 8 | Sphagnum tussocky upland | Baltic sphagnum | 65 | 0.5—0.15 | 0 |
| | | Narrow-leaf sphagnum | 10 | | |
| | | Cotton grass | 10 | | |
| | | Scheuchzeria | 10 | | |
| | | Rootlets of heath scrubs | 5 | | |

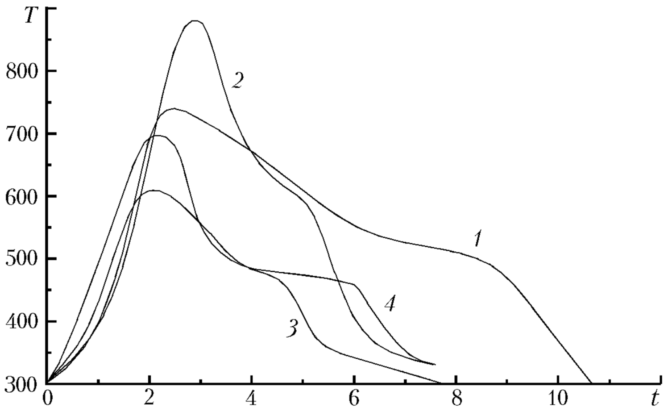

Fig. 2. Temperature of peat at various controlled points (1–4 are thermocouple numbers) vs. combustion time. $T$, K; $t$, sec.

**Determination of the Minimum Energy of Ignition of Peat.** Table 1 presents results of determination of the minimum energy of ignition for peat specimens taken from a depth of $(15–20)\cdot10^{-2}$ m. Clearly, with an increase in the peat density ($W = 0$) the minimum ignition energy increases (experiments 1–4), which is linked with heating of a large mass of peat up to the ignition temperature. The ash content of the specimens in experiments 1–3 remained about the same. A 31% decrease in the ash content (experiments 3 and 4) results in an 18% increase in $Q$ at the same peat density and porosity, which is indicative of the effect of the botanical composition of the specimens on the minimum ignition energy.

The next experimental run was conducted with the peat specimens with low values of the ash content $Z$ = 0.03–0.12, i.e., of peat with a larger completeness of combustion (experiments 5–7) and a broader range of variation of the density and porosity. In this experimental run, the peat remained dry ($W = 0$). Clearly, an increase in the peat density and porosity leads to a rise in the minimum ignition energy. However, at the low value $\rho = 0.38\cdot10^3$ kg/m$^3$ the magnitude of $Q$ increases to 81.25 J. The presence of air in pores decreases the effective thermal conductivity and prolongs heating of the peat specimens; therefore, they ignite later.

The presence of moist peat results in an increase in the minimum ignition energy $Q$ (experiments 8–12) in connection with the additional energy consumption on moisture evaporation. We direct our attention to the decrease in $Q$ when the amount of moisture is small (experiments 6 and 9), which provides more favorable conditions of heating of the peat specimens due to conduction, i.e., heat transfer into the specimen.

Table 2 presents values of the minimum energy of ignition for peat specimens with a different botanical composition (see Table 3), taken from various depths in the Bakchar forestry.

The divergence in the results given in Table 1 and 2 indicates a strong dependence of the minimum ignition energy on the moisture content and botanical composition of the peat. The values of $Q$ differ by an order of magnitude, which is linked with an increased moisture content of the peat specimens in the Bakchar forestry. Pine-cotton-grass and sphagnum tussocky upland peats have maximum ignition energies, regardless of the different degree of decomposition and depth of sampling, which can be attributed to the presence, in their composition, of the plant residue of cotton grass and narrow-leaf and Baltic sphagnum (experiments 4 and 8). Specimens of pine-sphagnum upland and fuscum peat ignite best (see experiments 3 and 7).

**Experimental Study of the Processes of Peat Combustion.** Figure 2 presents typical oscillograms of the peat temperatures at various controlled points (Fig. 3). As the fire front is approached, the peat temperature rises and reaches maximum values $T_{\max} = (683–873)$ K in the combustion zone, which is consistent with results of the full-scale experiment [3].

After ignition of the peat, the heat-flux density on the surface of the specimens is $q = (27{,}565 \pm 5342)$ W/m$^2$ at $\rho = 0.58\cdot10^3$ kg/m$^3$ and $W = 0.16$. The minimum ignition energy per unit area $S$ in a unit time $t$ is $q_{\min} = Q/(St) = 23{,}082$ W/m$^2$, which is in favorable agreement with the results obtained.

Table 4 gives results of determining the rate of combustion of peat as a function of its density and moisture content. Clearly, the effect of these characteristics on the combustion rate is appreciable. The dependence of the rate

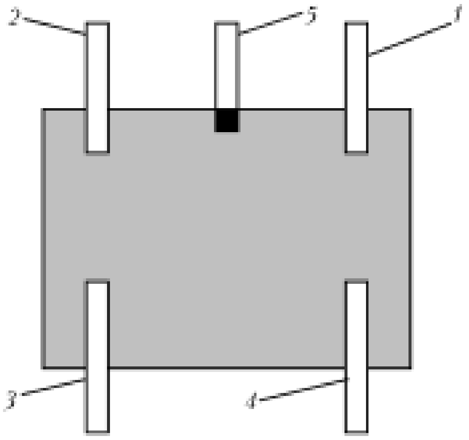

Fig. 3. Placement of thermocouples (1–4) and source of ignition (5) in a peat specimen for the experimental setup.

TABLE 4. Rate of Combustion of Peat as a Function of Its Moisture Content and Density

| Specimen number | $W$ | $\rho$, $10^{-3}$ kg/m$^3$ | $z$, $10^{-2}$ m | $v$, mm/min | $\pm\delta v$ |
|---|---|---|---|---|---|
| 1 | 0 | 0.38 | 0 | 0.7 | 0.10 |
| 2 | 0 | 0.58 | 0 | 1.2 | 0.15 |
| 3 | 0 | 0.78 | 0 | 1.0 | 0.20 |
| 4 | 0.15 | 0.59 | 0 | 1.0 | 0.09 |
| 5 | 0.23 | 0.58 | 0 | 0.6 | 0.12 |
| 6 | 0.42 | 0.57 | 0 | 0.1 | 0.10 |
| 7 | 0.42 | 0.38 | 2 | 0.7 | 0.15 |
| 8 | 0.42 | 0.38 | 8 | 0.8 | 0.21 |

of combustion of peat on the density is nonmonotonic (experiments 1–3). There is an optimum value of $\rho$, at which the combustion rate is maximum (experiment 2). At a low density, the combustion rate is low because of a deficiency of the combustible material and a low thermal conductivity of the peat. High values of density impede the filtration processes in peat pores that are associated with the oxidizer inflow and entrainment of combustion products (experiment 3). The presence of moisture (see experiments 1 and 4) increases the combustion rate by 30% (which can be explained by a rise in the effective thermal conductivity $\lambda_{ef}$), as is the case with the effect of low moisture contents on the minimum ignition energy. However, a subsequent increase in $W$ results in a sharp decrease in the combustion rate linked with the heat consumption on moisture evaporation. The rate of combustion of peat at a depth $z = 2 \cdot 10^{-1}$ m (experiment 7) is the same as that on the surface, and at $z = 8 \cdot 10^{-2}$ m it is 20% lower than on the surface, which is attributed to the increase in $\rho$ and inhibition of the oxidizer inflow to the combustible material through pores of the peat specimens.

The data obtained are in favorable agreement with the results of [3], in which the rate of combustion of milled peat under the conditions of natural convection is $v \approx 1$ mm/min at $W = 0.15$ and $v = 0.1$ mm/min at $W = 0.42$. Borisov et al. [3] attribute the difference in the combustion rates to dissimilar thermokinetic characteristics of peat, specifically, to the effective activation energy that for peat from a larger depth of occurrence is 25% larger. However, no mention is made of the peat density, which, as the experiments demonstrated, has a significant effect on the combustion rate. The results obtained are also qualitatively consistent with the numerical data of [4].

**Mechanism of Peat Combustion.** Visual observations indicate that under the conditions of natural convection peat burns in a flameless or smouldering mode. On ignition of peat, the fire front self-extends into the lower layers, which probably has to do with the difference in the density and filtration conditions and the ratio between the fuel and the oxidizer. The combustion front is inhomogeneous, the color of the products of peat combustion is gray-white, and the process is accompanied by smoke formation. The combustion temperature is $T_c = 618–873$ K, which agrees with the data of [3], where $T_c = 623–773$ K. The combustion temperature in a deep-lying peat layer is higher than on the burning surface, which is verified in [3]. The combustion rate depends on the moisture content, botanical composition, and density of the peat. This dependence is nonmonotonic.

The mechanism of peat combustion can be defined as a flameless diffusional one, with which the combustion rate is determined by filtration-diffusional processes of the oxidizer (air) supply through the porous structure of the peat to a dry combustible material. The suggested mechanism is supported by the nonmonotonic dependence of the combustion rate of combustion of peat on its density and by special experiments on peat ignition in an inert medium (the peat specimens were placed in a vessel filled with an inert gas, namely, argon; a standard source of ignition was mounted on the specimen surface, and here the process of peat ignition did not occur).

Analysis of the results obtained manifests that the minimum energy of ignition of the peat specimens depends on the botanical composition of the peat, its density (porosity), and the presence of moisture in it. There are critical values of the density $\rho_*$ and moisture content $W_*$ where their influence on the minimum combustion energy is of nonmonotonic character. This can be explained by the conditions of heat transfer into the peat specimens, by the value of the effective thermal conductivity.

## CONCLUSIONS

1. The values of the minimum energy of ignition of various peat specimens have been determined as functions of their botanical composition, moisture content, density, and ash content.

2. On the basis of experiments, the dependence of the rate of combustion of peat on the density and moisture content has been shown.

3. The mechanism of flameless diffusional combustion of peat that is due to the oxygen inflow from the ambient air through the porous structure of peat has been determined.

## NOTATION

$a$, thermal diffusivity of peat, W/(m$^2$·K); $J$, current, A; $m$, mass of the peat specimens, kg; $m_z$, mass of the burnt residue of the peat specimen, kg; $Q$, minimum ignition energy, J; $q$, heat-flux density, W/m$^2$; $T$, temperature, K; $t$, time of peat combustion, sec; $\Delta U$, voltage drop, V; $v$, rate of propagation of the peat fire front, m/sec; $W$, moisture content; $Z$, ash content; $z$, depth, m; $\rho$, density, kg/m$^3$; $\Pi$, porosity; $\lambda_{ef}$, effective thermal conductivity, W/(m·K). Subscripts and superscripts: c, combustion; f, final; z, residue; max, maximum; ef, effective; *, critical value; min, minimum.

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