The results of laboratory and field studies of thermophysical processes necessary for the occurrence of landscape fires in natural swamps

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Abstract. Investigations of the process of spontaneous combustion of peat depending on moisture content and its physical characteristics. One of the most important tasks is to ensure the environmental safety of human life. Ensuring the safety of the population and territories in emergency situations is now especially important, since the number of emergency situations is constantly growing due to vigorous human activity. Peatland fires are a serious problem in many countries with large forests.

1. Introduction
Smoke from landscape fires in high concentrations can spread over long distances. Such fires pose a threat due to smoke pollution of the territory, and intense heat radiation. Studies of the thermophysical processes of spontaneous combustion of peat are of practical importance for the prevention and elimination of such fires [1,8].

2. Materials and research methods
The article analyzes the data of laboratory and field studies of the effect of spontaneous combustion of peat with different physical characteristics and humidity. The temperature during the laboratory experiment was 90 °C, which corresponds to the possible heating of the surface layers of peat in natural conditions.

The rate of heat release with increasing temperature increases exponentially, and heat release is directly proportional. When the above processes are superimposed, boundary conditions are created at which the rates of heat removal and heat release are compared, and an imbalance occurs, as a result of which the effect of self-accelerating heating is observed, which entails combustion.

In the process of self-heating of an object, thermal energy enters the atmosphere through a surface with an area \( F \) (m\(^2\)). The amount of thermal energy passes through this surface per unit of time \( Q' \), which was experimentally obtained by I. Newton and has the form [2]:

\[
Q' = \alpha \cdot F \cdot \Delta T,
\]  

(1)
where: $\alpha$ - proportionality coefficient, or heat transfer (W m$^{-2}$ k$^{-1}$); $\Delta T$ - the temperature difference between the surface of the object and the environment.

The given dependence of the heat sink is linear.

As a result of oxidative processes with the participation of atmospheric air in peat samples, the initiation of the process of spontaneous combustion of organic matter is observed. This effect is exothermic and is characterized by the accumulation of thermal energy and subsequent self-acceleration [3].

Based on the results of laboratory experiments, algorithms for increasing the temperature in the center and on the surface of the tested samples were revealed at a known density and moisture content. The results of experimental experiments are presented in graphical form (figure 1). In the course of the research, the dynamics of changes in the moisture content of the studied peat samples was recorded.

3. Results obtained and their discussion

According to the results of laboratory studies, (figure 1) shows changes in the temperature of the thermophysical center and the surface of the tested peat samples, point 2, which shows that the temperatures of the thermophysical center, the surface of the samples and air are equal. The temperature readings here are borderline before the activation of the peat oxidation reaction, which is rapidly progressing and is a prerequisite for the development of spontaneous combustion. Thus, to assess the possibility of activating the spontaneous combustion process, the main thing is the achievement of peat samples of equality and temperature values at point 2.

The increase in the temperature readings of the thermophysical center at point 2 from the start of the experiment is divided into the following segments:

The first segment is located between the beginning of graph 1 and point 1. The temperature at point 1 is half of the ambient temperature reading. Humidity samples, point 1, are shown in table 1;

The second segment, located on the section point 1 - point 1.1, graphical dependence 1, is a straight section with a temperature that is numerically 1/2 of the ambient temperature. At point 1.1, the moisture content is 0% in the samples;

The third segment point 1 - point 2. Here the change in the temperature of the thermophysical center of the samples and the achievement of point 2 with a temperature in it equal to the ambient air temperature is noted.

Graphical dependence 2 describes changes in the surface temperature of peat samples and is divided into two segments. The first segment is a straight line from the beginning of the test and until the temperature reaches 45 °C, the second segment is a straight line in the continuation of the first and with a temperature of 45 °C to point 2 (figure 1).

![Figure 1](image-url)

**Figure 1.** Graphical dependences of changes in peat temperature. 1- center, 2-surface, 3-air temperature.
Table 1. Moisture content of peat at the points of the temperature curve of the center.

| Bulk density of peat g/cm³ | Initial moisture W₁₁₂ % | Moisture in p. 1 % | Moisture in p. 1.1 % | Moisture evaporation rate U g/min |
|---------------------------|--------------------------|-------------------|---------------------|-------------------------------|
| 0.16                      | 65.2                     | 52.9              | 0                   | 0.039                         |
| 0.18                      | 66.2                     | 55.4              | 0                   | 0.021                         |

Moisture in peat does not allow the temperature in the center to rise more than 1/2 of the ambient air temperature. As soon as the peat is completely dehydrated, the temperature of the thermophysical center begins to rise.

In the course of a field experiment in the Kalskoye swamp of Ryazan region, measurements were made:

1) the air temperature in the surface layer, soil surface 0 cm, in the center of the peat soil layer 0-5 cm, in the center of the peat soil layer 5-10 cm, in the center the soil layer is a layer of peat soil 10-15 cm;

2) moisture in the center of the layers of the peat soil layer 0 - 5 cm, 5 - 10 cm, 10 - 15 cm.

Table 2 shows the characteristics of the peat of the Kalskoye bog, which were determined in the soil laboratory, this peat soil was also used for the laboratory studies given above.

The temperature in the 0-5 cm layer was higher than the temperature in the 5-10 cm and 10-15 cm layers. In the 5-10 cm and 10-15 cm layers the temperature was lower than on the peat surface and in the 0-5 cm layer. Therefore spontaneous combustion in them was impossible.

The conditions that determine the thermal characteristics of peat soils are: chemical and mineralogical composition, dispersion, temperature, porosity and soil moisture. Moisture and porosity are the determining factors of the listed factors, which have a major impact on the thermal regime and characteristics of peat.

Taking into account the consumption of solar energy for the evaporation of moisture from the surface of the peat soil and turbulent exchange with the surrounding atmospheric air, we can say that the energy consumption for these transformations is from 95 to 98%.

Direct heating of the peat layer consumes about 2-5% of solar energy, which, in the presence of moisture in the peat, is diverted to the lower layers.

The main factors that determine the value of the radiation balance are the height of the sun above the horizon, cloudiness, atmospheric transparency and the state of the active surface (color, temperature, roughness) [4, 5].

The exchange of heat and moisture of the peat surface with the surrounding air layer occurs due to the fact that in any time interval the surface air layer in contact with the surface has a temperature and humidity that are different from the soil surface.

In the daytime, the main part of the radiation balance is short-wave radiation $R_\text{sun}$, at night it is absent and the balance is equal to the effective radiation of the earth.

The main part of the radiation balance is spent on turbulent heat exchange $P$ and moisture exchange $LE$ of the active surface with the environment [6, 7].

The values of total evaporation and turbulent heat transfer depend on the difference in temperature and humidity between the surface of the peat soil and the air, as well as on the structure, direction and magnitude of the wind speed, roughness and structure of the soil surface. In the absence of capillary feeding of the upper layer of peat soil, due to the low level of groundwater and the absence of precipitation, the upper layer of the soil begins to dry out.

The temperature regime of the soil is determined by the heat exchange of the active surface with the underlying layers and depends on the thermophysical properties of the soil, as well as on the distribution of temperature and humidity along the depth of the soil profile.

When the surface of the soil is covered with vegetation, part of the radiant energy is converted by the vegetation cover, namely: it is reflected by the surface of the leaves, heat is accumulated by the surface of the leaves, there is a flow of heat from the leaves into the atmosphere, transpiration.

Lowering the groundwater table leads to a decrease in evaporation due to a decrease in moisture. Desiccation of soil layers significantly reduces their heat capacity and thermal conductivity, which
reduces the flow of thermal energy into the lower layers by reducing the thermal conductivity coefficient. The albedo value for peat soils is 8-10% and 20-23% for soils covered with vegetation [8].

Table 2. Results of chemical analysis of peat samples from the Kalskoye bog.

| Determined indicators | Units of measurement | Research results | Error characteristic | Compliance with NTD requirements | Test Method |
|-----------------------|----------------------|------------------|---------------------|--------------------------------|-------------|
| Decomposition rate    | %                    | More than 50     | –                   | corresponds to                |             |
| Ash content pH        | %                    | 22.17            | ±0.80               | corresponds to                |             |
| Calcium (Ca) mg/kg    |                      | 34.34            | ±0.39               | corresponds to                |             |
| Magnesium (Mg) mg/kg  |                      | 1577.41          | ±7.43               | corresponds to                |             |
| Iron (Fe) mg/kg       |                      | 15110.21         | ±60.14              | corresponds to                |             |
| Sodium (Na) mg/kg     |                      | 1289.45          | ±16.00              | corresponds to                |             |
| Aluminum (Al) mg/kg   |                      | 5030.00          | ±14.80              | corresponds to                |             |
| Silicon (Si) mg/kg    |                      | 19.50            | ±3.59               | corresponds to                |             |
| Total sulfur mg/kg    |                      | 1.33             | ±0.13               | corresponds to                |             |
| Solid phase density g/cm³ |                | 1.37             | ±0.14               | corresponds to                |             |
| Total phosphorus  %   |                      | 0.38             | ±0.05               | corresponds to                |             |

4. Conclusion

The process of spontaneous combustion of peat occurs in the absence of moisture, which is illustrated in figure 1 and table 1, since the main heat energy is spent on its evaporation, and there is no violation of the heat balance, leading to the beginning of self-heating of peat.

Taking into account the consumption of solar energy for the evaporation of moisture from the surface of the peat soil, and turbulent exchange with the ambient air, it can be concluded that the energy consumption for these processes is 95 - 98%. For heating peat soil directly, about 2 - 5% of solar energy is consumed, which, in the presence of moisture in the peat layers, is diverted into the deep layers.

The entire thickness of the peat soil, during the field experiment, was in the zone of recharge with groundwater, which created moisture in the soil layers (figure 3), against the background of precipitation, which prevented the creation of conditions for spontaneous combustion of peat, since part of the thermal energy was spent on moisture evaporation.

Since the entire peat layer in the bog was in the groundwater recharge zone, thermal energy was also diverted to the lower layers of the peat bog, since the moist soil has a high thermal conductivity coefficient.

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