MATHEMATICAL RESEARCH INTO MOISTURE EVAPORATION IN A PEAT LAYER

A.I. Filkov, A.M. Grishin, D.A. Gladky
filkov@mail.tsu.ru
Tomsk State University, 36, Lenin av., Tomsk, 634050, Russia

Abstract
A one-temperature mathematical model for drying of a peat layer is proposed in the work. Peat is considered to be a multiphase media consisting of a dry organic substance, free and bound water, and gas phase. The finite difference method is used to solve numerically the mathematical model. The volume fraction of water, gas phase, and temperature of a peat layer versus time were obtained. It was investigated the influence of initial volume fraction content on the drying rate of a peat layer.

Introduction
Peat covers more then $4{\cdot}10^6$ km^2 (3 % of ground surface) and are the part of the earth ecosystem. In the world approximately 80 % of peat is located in the Nordic Region with a temperate climate. The total amount of carbon in peat exceeds the amount of carbon from all woods of the earth. When smoldering, peat releases mote than 30 % of CO_2 and more than 20 % of hydrocarbons in comparison with emission of hazardous substances from forest fires [1].

Peat fires occur regularly. Despite pouring rains or attempts of firemen it is very difficult to extinguish peat fires. Fires can last during the considerable periods of time (from a week and to several years) and cover very large areas. For example, over the last 50 years, extensive peat fires were registered in 1972, 1992, 2002, and 2010 only in the Moscow Region. According to the data presented by Emergency Situations Ministry, since the fire-dangerous period of 2010 there were 996 centers of natural fires on the area of 546 hectares in the Moscow Region, and 443 of which were peat fires. According to the official figures, it was registered daily almost 50 centers of peat fires in Moscow area.

Despite the negative consequences of peat fires, by the present time, it has not been developed yet a scientifically based system for the prediction of fires, which could estimate the probability of peat fires, including natural and anthropogenic loadings, characteristics of area and soil cover, and meteorological conditions as well.

Mathematical model
According to [2], it is necessary to specify the following basic factors influencing on the initiation of ground wood and peat fires:

1. Ability of fuel to ignition; that is a state when fuel can ignite from an external source of fire.
2. Ability of fuel to fire propagation; that is a state when fire can spontaneously propagate along the layer of fuel.
3. Availability of natural and anthropogenic sources of fire.

It is of great interest to investigate the influence of the first and second factors mentioned above. It is obvious, that they are directly connected with the moisture content and drying of fuel. Besides, it should be noticed that the moisture content of fuel permitting to be ignited and the moisture content permitting the fire to propagate along the layer of fuel without additional energy sources, are different. In addition, these values are various for various kinds of fuel. Therefore, a solution of the problem on drying of fuel takes the important place in the prediction of fire hazard.

The characteristics of the peat layer for the specific area allow fire hazard to be estimated and calculated also for all places in the area under study, which, in turn, will allow us to use optimally the resources directed towards the prevention and suppression of fire.

We assume that a layer of peat is dried under the influence of environment. It is considered the one-dimensional problem in the Cartesian coordinate system; the Z-axis is directed straight down, the origin of Z-axis coordinates is chosen at the interface of peat layer and atmosphere. A mathematical model for drying of a peat layer is one-temperature, i.e. the gas and condensed phases (carcass) have the identical temperature.

Since a peat layer is dried in the nature at low temperatures (up to 50 □C), we assume that free water is evaporated in the layer of peat. Peat is considered to be a multiphase media consisting of a dry organic substance with a volume fraction φ_1, free and bound water with a volume fraction φ_2, and a gas phase φ_3. We considered the layer of peat with a small initial volume fraction of the gas phase φ_{3H} ($0.1 < \varphi_{3H} < 0.2$) in contrast to the volume fractions of the condensed phase. This mathematical model is a particular case of the model offered in [3].

The mathematical problem, formulated above, taking into account the made assumptions is reduced to the solution for the following set of equations:

$$\frac{\partial \rho_3 \varphi_3}{\partial t} + \frac{\partial \rho_3 \varphi_3 v}{\partial z} = Q, \tag{1}$$

$$v = -\frac{\xi}{\mu}\frac{\partial P}{\partial z}, \quad P = \frac{\rho_3 R T}{M_3}, \tag{2}$$

$$\sum_{i=1}^{2} c_{pis}\rho_{is}\varphi_i \frac{\partial T}{\partial t} + c_{p3}\rho_3\varphi_3\left(\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial z}\right) = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) - q_{2s}R_{2s}, \tag{3}$$

$$\varphi_1 = \varphi_{1H}, \quad \varphi_3 = 1 - \varphi_1 - \varphi_2, \tag{4}$$

$$\rho_{2s}\frac{\partial \varphi_2}{\partial t} = -R_{2S}, \tag{5}$$

$$Q = R_{2s}, R_{2s} = \frac{\rho_{2s}\varphi_2 k_{2s}\exp(-E_{2s}/RT)}{\sqrt{T_2}}. \tag{6}$$

To solve the set of equations (1) - (6), it is used the initial and boundary conditions:

$$T|_{t=0} = T_H, \quad \rho_3|_{t=0} = \rho_{3H}, \quad \varphi_i|_{t=0} = \varphi_{iH}, \quad i = 1,2. \tag{7}$$

$$P|_{z=0} = P_e, \quad \frac{\partial P}{\partial z}|_{z=L} = 0, \quad \lambda\frac{\partial T}{\partial z}\Big|_{z=0} = \alpha_e(T_e - T_w) + \varphi_{sw}q_{rw} - q_{2s}R_{2s}, \quad T|_{z=L} = T_H. \tag{8}$$

Here t is the time, z is the spatial coordinate, Q is the mass velocity of the gas phase formation; c_p is the thermal capacity coefficient, k_{2s} is the preexponential factor of the evaporation reaction, E is the activation energy characterizing water evaporation, M is the molar weight, P is the gas pressure in pores, R_{2s} is the mass evaporation rate of free and bound water in peat, q_{2s} is the thermal effect of reaction R_{2s} , R is the universal gas constant, T is the peat temperature, v is the rate of gaseous evaporation reaction products, $\mu = \mu_н (T / T_н)^{0,5}$ is the dynamic viscosity coefficient of a gaseous mixture, $\xi = \xi_* \varphi_3^3 /(1-\varphi_3)^2$ is the function describing the influence of a volume fraction on resistance, φ_i , i=1,2,3 is the volume fraction, ρ_i, i=1,2,3 is the density, λ is the thermal conductivity, α is the heat transfer coefficient, q_{rw} is the flux density of built-up radiation at the interface of media. Indexes: s is the condensed phase, e is the environment, H is the initial value, w is the state parameter for z=0, i=1,2,3 is peat, free and bound water, water vapors.

The set of equations was solved numerically by the finite difference method with the constant time step according to the technique described in the work [4]. The results of calculations were compared with experimental data [5, 6].

Results

The model described above allows us to obtain the volume fraction of water, gas phase, and temperature of a peat layer versus time. It was investigated the influence of the initial volume fraction content on the drying rate of a peat layer. The received numerical results are in a good agreement with experimental data.

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