Mathematical Modeling of Coniferous Tree Ignition by Ground Lightning Discharge Taking into Account Localization of Reactive Wood

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1 Introduction

The mathematical models adequate to the real physical mechanism of tree ignition by ground lightning discharge [1] have not created till now. Polarity, a peak current and voltage, and also duration of action are the basic characteristics of ground lightning discharges [2]. The average peak current can reach [3]: J=23.5 кA for the negative discharge and J=35.3 кA for the positive discharge. Essential structural heterogeneity is one of the important factors which among many should be considered at the analysis of conditions of real wood ignition. Non-uniform distribution of branches on length of a tree trunk should influence to conditions of discharge passage and accordingly, intensity of a warming up and reach of ignition conditions. For this reason modelling of process of coniferous tree trunk wood warming up under the influence of a lightning discharge in two-dimensional statement is expedient. The purpose of the present research is determination of coniferous tree ignition conditions by a ground lightning discharge depending on parameters of the discharge taking into account not one-dimensional process of heat distribution in a trunk.

2 Physical and mathematical statement of a problem

Electric current course has the features in case of a lightning stroke in a tree trunk of coniferous breed, as resistance of directly wood of a resinous tree much more, than a bark and a subcrustal layer. Therefore the electric current of the lightning discharge passes in a coniferous tree trunk mainly on external layers, not getting inside. Special interest represents research of heat transfer taking into account localisation of so-called reactive wood. Such wood is formed in the bottom part of branches at coniferous trees and is called still as wood of compression [4]. Reactive wood differs from usual physical and chemical properties [4]. For the description of modelled process the following physical model is accepted. Separately standing tree of coniferous breed is considered. Lightning discharge of certain polarity and duration of action strikes in tree trunk during the fixed moment of time. It is considered, that volt-ampere characteristic of the discharge are identical in various sections of a tree trunk. The warming up of trunk wood occurs at the expense of Joule heat allocated in a subcrustal zone of a tree trunk. There is a warming up of wood as a result of electric current course. Tree ignition is reaching critical heat flows from subcrustal zone of a trunk to surface of ignition and its temperatures. Influence of moisture content of wood on ignition process is neglected. The decision area is presented on fig. 1 (Left) where figures designate areas: 1 - a tree trunk core; 2 - a subcrustal zone; 3 - a tree bark; 4 - wood of the top part of branches; 5 - reactive wood of the bottom part of branches; 6 - a part of a subcrustal zone which has the same properties as area 4; 7 - a part of a subcrustal zone which has the same properties as area 5; 8 - a part of a core which has the same properties as area 4; 9 - a part of a core which has the same properties as area 5; 10, 11 - air. Borders of areas are designated on fig. 1 (Right).

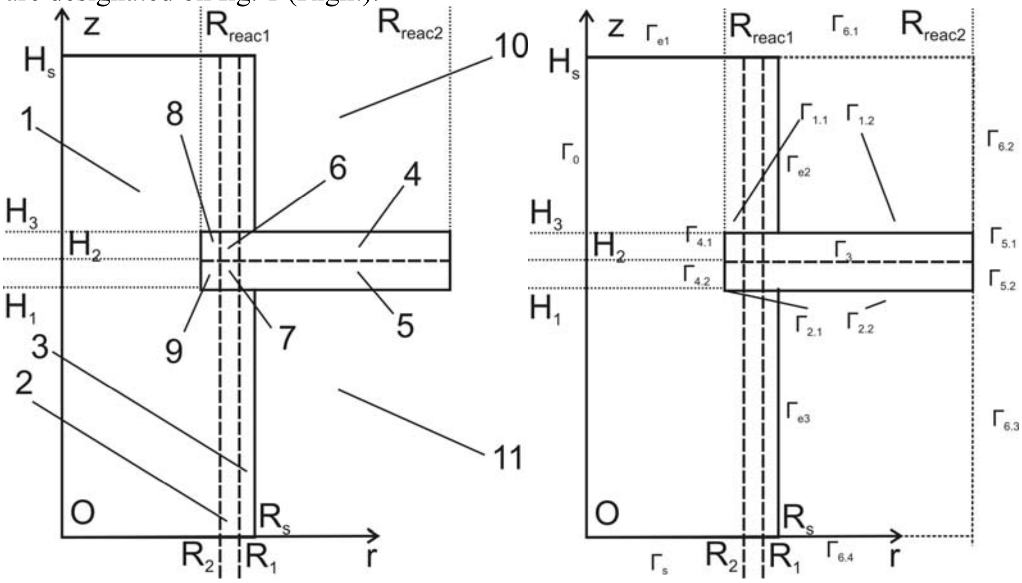

Figure 1. Geometry statement. Left: The scheme of decidion area. Right: Borders of subareas. R_s - external radius of a trunk, R_1 - border of bark section and a subcrustal zone, R_2 - border of core trunk section and a subcrustal zone, H_s - tree trunk height, H_1H_2 - a thickness of reactive wood zone (the bottom zone of a branch), H_2H_3 - a thickness of the top branch zone, Γ_i, $\Gamma_{i.j}$ - designations of areas borders.

Heat transfer in considered system is described by means of the heat conductivity non-stationary equations. Temperature field is constant in the initial moment of time. 4^{th} sort boundary conditions (equality of heat flows) are exposed on the borders of subareas. 3^{rd} sort of boundary conditions are exposed on border of the decision area.

3 Results of numerical modeling and discussion

The formulated system of the equations with boundary and initial conditions is solved by locally one-dimensional finite-difference method [5]. Sweep method [5] was used for the decision of difference analogues of the one-dimensional equations. The typical scenario of ignition is considered – ground lightning discharge of negative polarity strikes in a pine trunk. Duration of discharge is 500 мs with a peak current 23.5 кA and voltage 100 kV. Temperature distribution on radius and height of coniferous tree trunk presented on fig. 2 to the various moments of time. Dependence on time of heat flow from subcrustal zone of tree trunk at various height from land surface are shown on fig. 3 (Left). Dependence of tree trunk subcrustal zone border temperature from time at certain levels over an land surface is presented on fig. 3 (Right). Curves 1 and 2 for usual (z=8.2) and reactive (z=8.47) wood are designated on fig. 3 accordingly.

Experimentally certain conditions of ignition is offered to use as criteria of ignition in the present work (table 1 [6]) . Given conditions numerically were defined for usual and reactive wood within the limits of considered research. The similar approach in definition of ignition conditions is used in work [7].

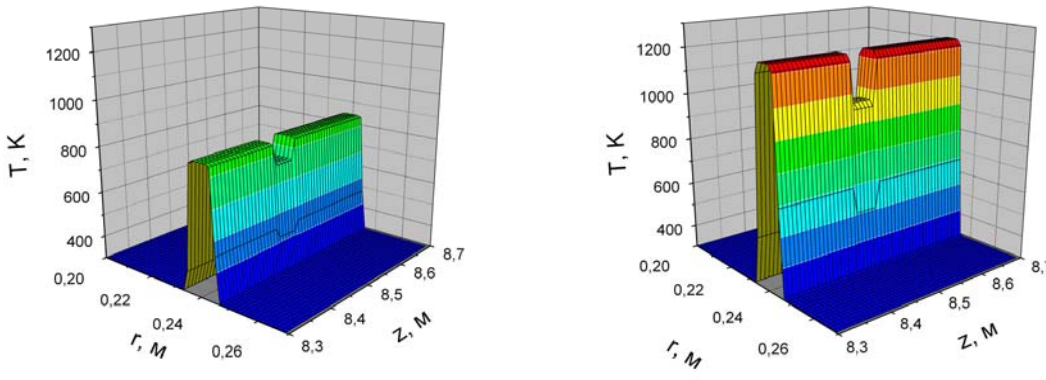

Figure 2. Temperature distribution on radius and tree trunk height during the various moments of time. Left: t=0.3 s. Right: t=0.5 s.

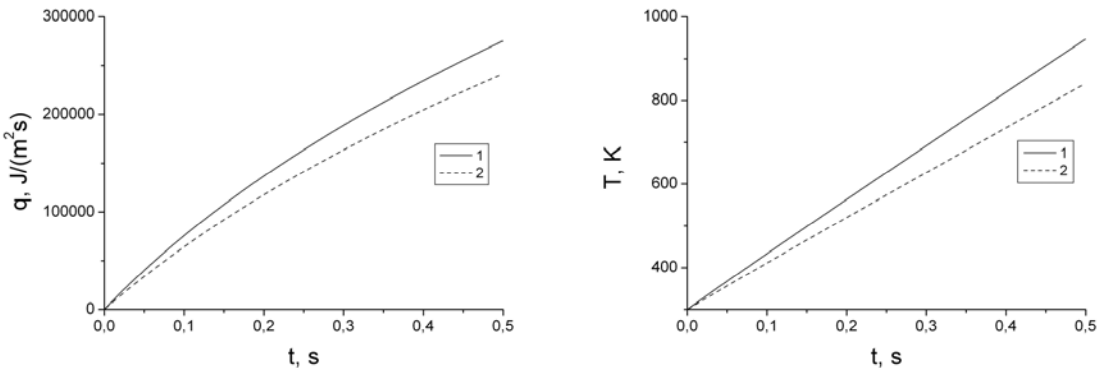

Figure 3. Ignition condition. Left: Dependence of a heat flow from a subcrustal zone to a surface of ignition from time. Right: Dependence of subcrustal zone border temperatures from time. 1 - usual wood (z=8.2 m, r=0.244), 2 - reactive wood (z=8.47 m, r=0.244)

Table 1: Experimentally certain conditions of pine ignition [6]

Time of a ignition delay, s	Heat flow, kW/m^2	Surface temperature, K
63.5	12.5	658
45.0	21	700
11.1	42	726
2.6	84	773
0.4	210	867

Research of influence of volt-ampere characteristics of a ground lightning discharge on process of coniferous tree trunk ignition have been carried out.

The analysis of results shows, that the typical ground lightning discharge with parametres (U=100 - 110 кВ and J=23.5 - 35 кА) causes ignition of coniferous tree usual wood. It is possible to make a conclusion, that the majority of ground lightning discharges causes ignition of coniferous tree usual wood. However, conditions of ignition [6] are not always reached for reactive wood at their simultaneous performance for usual wood. Differences in thermophysical properties explain differences in temperature of usual and reactive wood. Thermophysical properties of usual wood: $\rho=500\ kg/m^3$; $c=1670\ J/(kg\cdot K)$; $\lambda=0.12\ W/(m\cdot K)$. Thermophysical properties of reactive wood: $\rho=550\ kg/m^3$; $c=1670\ J/(kg\cdot K)$; $\lambda=0.12\ W/(m\cdot K)$. Thermophysical properties of subcrustal zone: $\rho=650\ kg/m^3$; $c=2600\ J/(kg\cdot K)$; $\lambda=0.35\ W/(m\cdot K)$. Length of a branch - 30 sm. Thickness of a branch - 10 sm.

It is established within the framework of this research, that geometrical parameters influence mainly to the size of a field of lower temperature in the zone of reactive wood. It is established at parametrical research of influence of voltage of a lightning discharge that only at voltage 110 kV and performance of ignition conditions [6] is above observed. The similar variation of ground lightning discharge current has shown, that ignition conditions [6] are above reached only at a current 30 кA. As a result of action of a considered ground lightning discharge the tree trunk in a subcrustal zone is warmed up to temperatures (fig. 2) at which forest fuel burn (more than 1200 K). The tree trunk ignites in considered conditions. A logical consequence of distinctions in thermophysical properties of usual and reactive wood is lower field of temperature in the zone of reactive wood with other identical conditions. The ground lightning discharge with average volt-ampere characteristics cannot lead to ignition of coniferous tree reactive wood. It is not possible to consider this effect within the limits of one-dimensional statement [7].

4 Conclusion

The important scientifically-practical problem is solved. The physical and mathematical model of coniferous tree ignition taking into account localization of reactive wood is developed. Ignition conditions, characteristic for a typical range of change of parameters of lightning discharge are established. Area of lower temperature is formed in a zone of reactive wood and as consequence it is possible to expect, that the lightning discharge with identical volt-ampere characteristics will lead more possibly to ignition of high trees with small quantity of branches. And on the contrary ignition of trees with the developed system of branches and boughs is improbable. The obtained results create conditions for the further development of fire-dangerous materials ignition models and determined-probability approaches to an estimation of fire danger in forests.

References

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