Main gas and thermodynamic characteristics of the convective flow in wildfires

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Based on the integral method were defined parameters of convective flow, appearing during a wildfire. As result we obtain data for the maximum speed, temperature and density variations depending on power of fire and the impact of the wind speed. Used approach gives an opportunity for a fast analysis on a real wildfire in forest areas. This could help fire management to make crucial decisions effective activities in order to take the fire under control and extinguish it. This method allows predicting future critical situations with potential health treats for fire crew and population in the area. It is also useful tool for prediction the direction of fire front development..

Key words: *Integral method, Forest fire, Wildfire, Convective flow, Fire management, Fire development.*

INTRODUCTION

Crucial for the development and the speed of movement to the front of a wildfire are many different factors such as the quantity and moisture content of combustible materials, their vertical and horizontal distribution. Other inportant parameters are also such as the terrain and the presence of natural and artificial barriers in the way of offensive of the fire. The presented above are subjects of evaluation and research before the occurrence of fire. Much more difficult is to study the dynamic effect of the wind, which can change the direction and strength repeatedly in the development process of it (Fig. 1). In combination with all the other factors that considerably complicates the task of prognosis the speed of propagation of fronts of the wildfire in order to support the planning and execution of extinguishing actions.

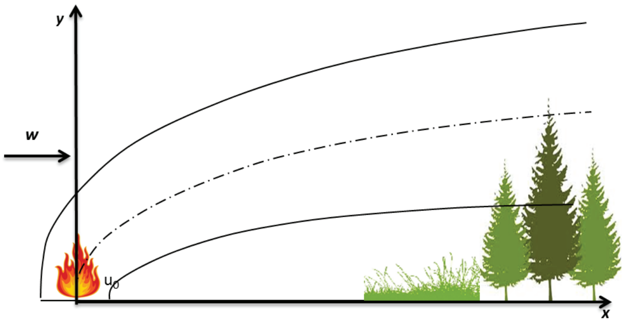

Fig. 1. Tilting (bending) of the gas flow to the ground

One of the most significant aspects of the impact of the wind velocity is the possibility fronts of the fire to overcome on its way of development zones and areas of non-combustible materials. This effect is achieved by tilting (bending) of the gas flow to the ground which is a mixture of strong hot products of combustion, unburned solid particles and other impurities. The inclined flow acts as a rapidly reduction of moisture content in the combustible materials in the frontal boundary of the fire. Thus accumulated combustible mass is prepared for easy ignition and require less energy for the occurrence of combustion in the corresponding solid combustible materials.

The gas flow has a high temperature at a considerable distance from the zone of combustion. In the absence of wind, it would mean intensive heat release at a height above the front of the fire, but deformed (tilted to the ground) this means providing a stream of high temperature flow at a distance from the front of the fire.

MATHEMATICAL MODEL

The science investigation and the mathematical description of the wildfire phenomenon lead to the mathematical model based on an integral method determining the parameters of the convective flow. In this case the usual radiation heat transfer is ignored because of it's an insignificant value than the wind influence at an open space zone. For ease of calculation may introduce limits on the temperature of the gas stream and the height of the boundary layer. When the mentioned parameters are out of these boundaries it can be assumed that the temperature of the gas stream of the height of it is harmless.

The velocity of the convective flow in the initial moment above the burning zone is determined by the power of fire in dependency:

$$u_0 = 1{,}9Q^{1/5} \tag{1}$$

where Q is the power of the fire measured in KW.

In certain values for the wind velocity the jet axis may become parallel to the ground [5]. The process of changing the direction of movement as a final result is bent flow whose longitudinal axis l at the initial moment is perpendicular to the ground surface and gradually turns into a horizontal direction. In the step of horizontally arrangement it is essential the distance between the position of the center of the gas stream and the ground surface. At wind speed equal or greater than 5m/s, the width of the burning strip is about 4 to 10m., the power of the fire is between 200 KW and 500 KW, and then the gas stream becomes parallel to the ground surface at a distance less than its radius. It is necessary to calculate the rate of fading temperature of the products of combustion in the gas flow to evaluate the level of danger.

Bent in the wind axis of the gas flow over the fire takes the form shown on Fig. 1. The parameter l measured in meters on a distance x from the combustion process is determined by the following equation:

$$l = \int_{\partial}^{x} \sqrt{1 + y'^{l}}\, dx \tag{2}$$

or:

$$l = x\sqrt{1 + y'^2} \tag{3}$$

where:

$$y'^2 = \frac{1}{kx + ctg^2 \alpha_0} \tag{4}$$

where α_0 is the initial slope of the flow.

The coefficient k is defined by:

$$k = \frac{\rho_{вят}\, W_{вен}^2}{b_0\, \rho_{cm,0}\, V_0^2 \sin\alpha_0} \tag{5}$$

When the angle is $\alpha = \dfrac{\pi}{2}$ and $\sin\alpha_0 = 1$, then:

$$k = \frac{\rho_{вят}\, W_m^2}{b_0\, \rho_{cm,0}\, V_0^2} \tag{6}$$

After obtaining the results for l it is possible to calculate the rate of the temperature fading in the volume of the convective flow. It is assumed that the temperature is uniform over the entire cross section of the flow without taking into account the cooling around the circumference, caused by mixing with ambient air. The obtained result gives a rough idea of what distance at the given power of fire and wind velocity there is a potential risk of ignition of combustible materials typical of forest and field arrays. The dynamics of increase in the diameter of the convective flow can be calculated by:

$$b = b_0 + 0,22l \tag{7}$$

The maximum velocity fading by l can be calculated by a modified equation [3]:

$$\overline{u_m} = A_u n^{-\frac{1}{2}} \left(\frac{l}{b_o} \right)^{-\frac{1}{2}} \tag{8}$$

where $n = \rho_w / \rho_0$; $A_u = 2,48$ is an integral obtained by integration of the cross section velocity [4].

The fading of the density of the gas flow along the length l is determined by:

$$\Delta\overline{\rho}_m = \frac{\Delta\rho_m}{\Delta\rho_o} = A_p n^{\frac{1}{2}} \left(\frac{l}{b_o} \right)^{-1} \tag{9}$$

or:

$$\Delta\overline{\rho}_m = \left(\rho_w - \rho_l \right) / \left(\rho_w - \rho_o \right) \tag{10}$$

In this case $\rho_w - \rho_o = 0,8$, therefore $\rho = \rho_w - 0.8\Delta\overline{\rho}_m$

The temperature of the convective flow is going down after satisfying the condition:

$$\rho_l > \rho_0 \tag{11}$$

The temperature of the gas flow along the center line of the streat is obtained in Kelvins by:

$$T_l = p / \left(\rho_l R \right) \tag{12}$$

where $p = 10^5 Pa$ is the atmospheric pressure; $R = 287 J / kg^o K$ or $R = 292,6 J / kg^o K$ is the universal gas constant.

At lower wind velocity in range of 2 m/s, the flow does not tilt in the vicinity of the ground surface, but creates the prerequisites for a transfer of up to a higher positioned combustible material and creating a peak conditions for forest fires. At high wind velocity the hot flow sticks to the ground surface, intensively heating ground combustible materials, and create conditions for accelerated movement the front of the fire. This process takes place enormously, igniting ever greater areas and is increasing the intensity of the fire.

RESULTS

From the graphical results on Fig 2 – Fig. 7 are shown some of the computed parameters depending on the distance from the front of the fire and wind velocity. This information is important to predict and to describe the development of the fire, as these scenarios can be used with parameters such as linear speed of movement of the respective fronts on solid combustible materials. The initial parameters or the shown results are: $Q = 400KW$; $b_0 = 3m$

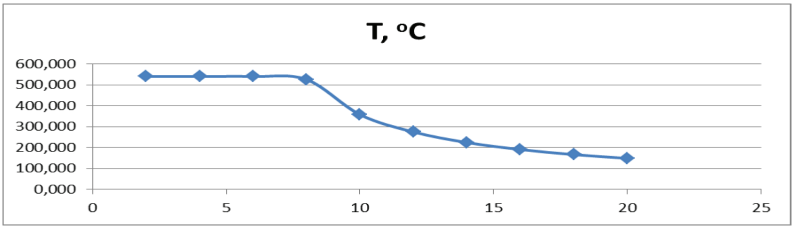

Fig. 2. Temperature fading of the gas stream at wind speed 2 m/s

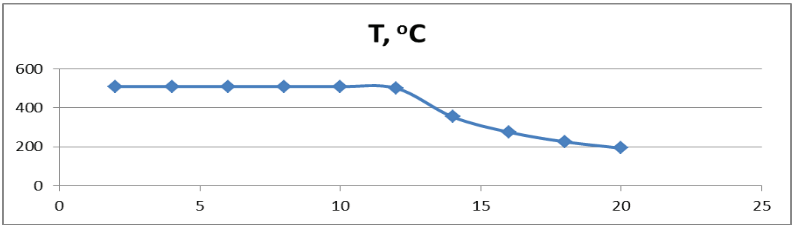

Fig. 3. Temperature fading of the gas stream at wind speed 10 m/s

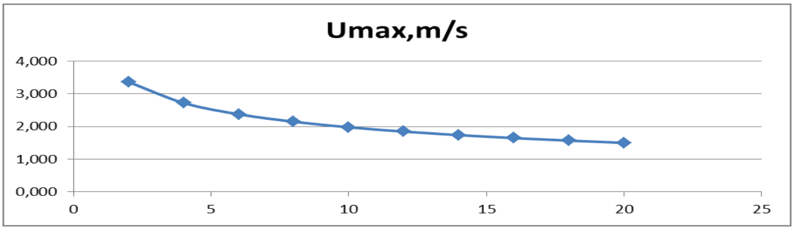

Fig. 4. Rate of the gas stream fading at wind speed 2 m/s

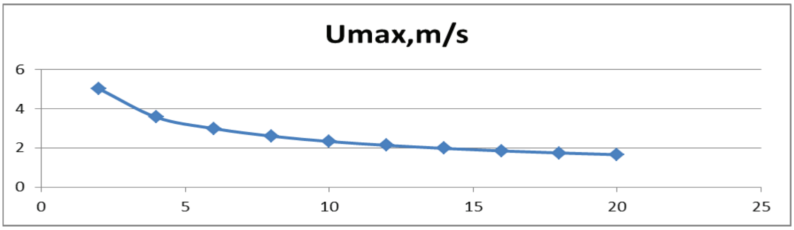

Fig. 5. Rate of the gas stream fading at wind speed 10 m/s

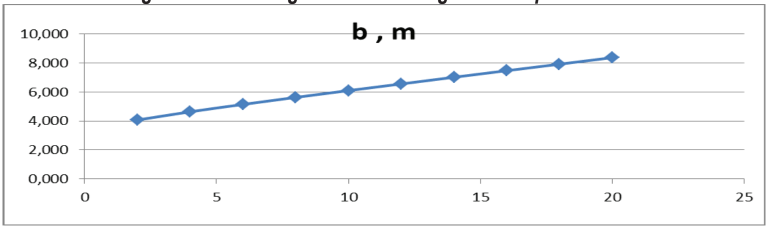

Fig. 6. Increasing the width of the boundary layer at wind speed 2 m/s

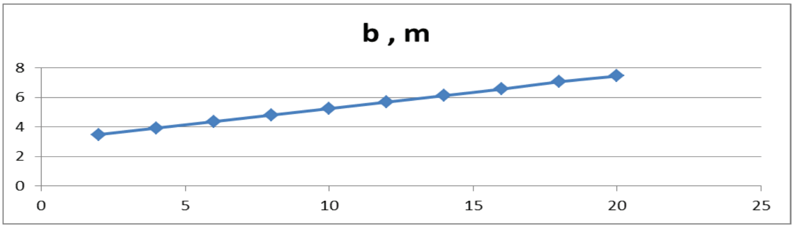

Fig. 7. Increasing the width of the boundary layer at wind speed 10 m/s

CONCLUSIONS

At relatively low wind speeds of 2m/s the temperature of gas flow falls below 300 ^{o}C by distance of 11 meters away from the front of the fire, therefore, the width of fire lane that can be overcome in the development of forest fire and the presence of exactly this wind speed is approximately 11 meters. By the given results of the calculations and those presented in [5] and less marked tilt of the flow there is a grave danger of fire spreading to higher bushes and trees.

At higher wind speed of 10 m/s the temperature of gas flow falls below 300 ^{o}C at a distance of 15 meters away from the front of the fire, therefore, the width of fire lane that can be overcome in the development of forest fire and the presence of exactly this wind speed is approximately 15 meters.

By the obtained results in this work and those presented in [5] and strongly expressed tilting of the flow at a higher wind velocity there is a significant danger of fire spreading also on paved on ground combustible materials and dry grass.

In terms of continuity of combustible materials the presence of a wind contributes to an accelerating movement of the front of the fire and the available barriers and areas of non-combustible materials is not an obstacle transfer the fire through these barriers.

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This paper has been reviewed.