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PARAMETERS OF THE LABORATORY MODEL TERRESTRIAL FOREST FIRE CREATED FROM THE NEEDLES OF PINE (*PINUS NIGRA*)

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ABSTRACT

The work deals with the monitoring of selected parameters in the model of terrestrial forest fire, which originated in forest litter (natural challenged material). A needle of black pine (*Pinus nigra*) was used as a fuel. For the model there was developed forest fire apparatus - wind tunnel, which simulates terrestrial forest fire on the basic model Superior Técnico in Lisbon (Portugal). In the apparatus, there is possibility to placing a sample on the basis of changes of coniferous litter and regulate the speed of the airflow over the layer of litter. The work reviews the effects of air velocity depending on time and temperature of coniferous leaf litter on the wind tunnel and the speed of flame propagation along the coniferous litter layer. In the article, there are original work results which show a significant effect of air flow over the surface of coniferous litter on a fire and the flame propagation speed after layer of litter. Threshold limits of the flow rate of air are in the range <0.5 $m \cdot s^{-1}$, 1.0 $m \cdot s^{-1}$>, in which there is an increase in linear speed of the spread of fire of 2 to 2.5 times. Subsequently, the linear speed of spread for models of terrestrial forest fire appeared significantly comparable at air speed 1.0 $cm \cdot s^{-1}$ and 2.5 $cm \cdot s^{-1}$. But time which shows spread of fire at specified speed has been reduced by 60% from the time of fire development at a speed of 0.5$cm.s^{-1}$.

KEYWORDS: Model terrestrial forest fire, fire spread rate, wind effects.

INTRODUCTION

Abiotic agents are the most contributing to the destruction of forests, that means a fire, too (thus forest fires), then biotic and anthropogenic factors. Currently, spruce, fir and pine are the most endangered tree species (Bútora et al. 2013).

Forest fires have special position in the environmental for its unpredictability, complexity of fireworks, the deployment of heavy equipment and a large number of intervening firemen and environmental impact on the surrounding environment (Simonson et al. 2011). Regardless of the current debate in the councils of environmentalists and defenders, we must accept the existing risk of forest fire and its subsequent spread into the environment. Issues about propagation speed of arising fires plays a key question in assessing of risk of fire creation and fire spread (Tuček and Majlingová 2009).

It is necessary to create appropriate models for simulating the purpose of planned development incurred adverse events, while we are accepting the evaluation of forest fire as soon as partially or totally adrift in time and space bounded incident which has a negative impact on all the social functions of the forest (Majlingová 2015). It is in general accepted that the cause of forest fires are mainly natural conditions and people themselves (Hlaváč et al. 2006). In the division of forest fires (Hlaváč et al. 2006) to the subterranean, terrestrial, crown and fire of hollow tree, there is attention directed to terrestrial fire that spreads through leaf litter, natural challenged materials. Oravec (2011) describes the essence of forest fire by means of appropriate material composition, suitable conditions and the ability of the material to transmit heat. The surface of the material is the most exposed surface from the point of view of heat transfer (Gaff et al. 2014, Kminiak and Gaff 2014, Miftieva et al. 2016). The heat is here supplied by conduction from the adjacent burning layer, convection of hot products of combustion and radiation from the flame. The surface material is also the most easily accessible to contact with atmospheric oxygen. Under favorable conditions (strong enough ignition sources, formation of flammable fumes degradation, sufficient oxygen) there it occurs in promoting the burning process, mainly to the flaming burning. Flame spread is essentially a continuous process of gradual ignition of new sections of material, which occurs spontaneously (Oravec 2011). In 2005 Fitzgerald realized a detailed analysis of the current state of pine ecosystems, namely ponderosa pine in Montana and showed to the need to reduce the formation of the respective layers of litter as a dominant cause of forest fires. The issue of forest fires was also concerned by Lanďák et al. (2012), who describes the development of forest fire under strong influence of external conditions and highlights the dominant airflow rate, which effects on the development of the intensity of the fire.

The weather as instantaneous state of the atmosphere significantly determines the emergence and spread of fire, so the assessment of risk of forest fires is monitored by meteorological elements (temperature, humidity, precipitation, wind) (Fischer, et al. 2015, Strickland 2012). Meteorological fire danger indices are the results, they are solved with a mathematical calculation (Sharples et al. 2009, Per Bak et al. 1999, Gutiérrez 2013)

The consequences of forest fires have an impact on all components of the environment, particularly forest biota as biotops, plant and animal components. Research of forest fires is promoted at the forefront through the appropriate experimental and mathematical models. (Fernandes 2014, Lotan et al. 1985)

It is still a need to pay attention to the research of forest fires through mathematical and physical models as well as laboratory models simulating behavior of fire in the natural environment within the existing models of forest fires for the purpose of understanding of the behavior of fires in the natural environment. (Hlaváč et al. 2007, De Angelis et al. 2015, Jurdao et al. 2011).

The aim of this paper is to create a model of terrestrial forest fires in laboratory conditions. Model terrestrial forest fire is simulated on the surface of the litter in the air wind tunnel. This model is used for monitoring method and speed of the spread of forest fires, depending on air flow in the tunnel. Quantified dependence between air velocity and linear velocity of propagation terrestrial forest fire is based on realized experiments.

MATERIAL AND METHODS

Model of terrestrial forest fire

The realization was carried out based on the results of modeling of forest fire by Morandini et al. (2001) and Simeoniho et al. (2001), which was based on experiments which were carried out by I.N.R.A. Laboratory of Avignon (France) and the Superior Tecnico Lisbon (Portugal). It was prepared device for modeling of the fire on the surface of litter (forest waste needles, leaves etc.), which is in the wood as the outermost layer of humus cover in the first stage of decomposition).

Components have been used as dendromass that occur in the administration of the University forest company of Technical University in Zvolen, Zvolen LHC k. ú. Kováčová. Sampling of litterfall (litter) was conducted in stands of number 463, 373b and 427. It is a black pine needles (*Pinus nigra*). Moisture value of samples was determined by gravimetric analysis and combustion heat by calorimetry method (Tab. 1). The modeling of terrestrial forest fire occurs in a wind tunnel with shape of cuboid 1500 x 800 x 800 mm (L x H x W), and is made of iron sheet metal skeleton and detachable walls.

Ending for truncated pyramid with a square-shaped opening for an artificial source of air flow (blower) in size 500 x 500 mm is on the back side of the tunnel. Fuel reservoir for model of terrestrial forest fire (fuel bed by Simeon et al. 2001), also referred to as "fuel reservoir" has a total area of 0.5 square meters. It is laid on the bottom in the tunnel in the center of the device, 150 mm from lateral sides, 350 mm from the edge and 550 mm from the ventilator propeller. There were produced three interchangeable reservoir which can be set to various angles considering the tunnel pad (slope). In the fuel holder there were three of them in a centered axis, at a distance of 250 mm, 750 mm and 500 m from the start of the substrate and thermocouple positioned into so the fuel inside the cartridge is to be protruded to a 20 mm height from the surface, thus on the bottom of the fuel reservoir. Thermocouples were positioned upstream from the initiation place of fuel combustion (Fig. 1). Device Testo 452 Testoterm was used to measure air velocity and for measure the temperature in modeling forest fires there were used devices Almemo 2290-8 and Almemo 2590-4S.

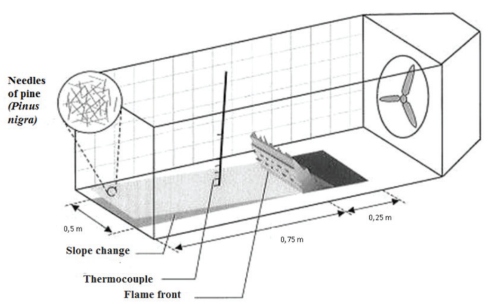


Fig. 1: Scheme of wind tunnel with a description of the individual parts.

A sample of weight 0.250 kg was evenly spaced on the surface of the fuel reservoir. The fuel reservoir with the imposition experimental sample was saving from the horizontal position through a tilt angle. Naphtha was used as initiator. The experiment was subsequently initiated by an external source (flame of a light) and simultaneously with the initiation there has been measured time of burning and spread of fire on the layer samples. Experiments were realized in order to monitor the manner and speed of the spread of forest fires, depending on air flow in the tunnel. Three air velocities were chosen in the wind tunnel for this purpose, and 0.5 $m \cdot s^{-1}$, 1.0 $m \cdot s^{-1}$ and 2.5 $m \cdot s^{-1}$.

Tab. 1: Parameters of samples the needles of pine (Pinus nigra) and conditions for laboratory model terrestrial forest fire.

Fuel reservoir	**Parameters of the sample**			**Experiment conditions**			
Series of measure-ments	**MC (%)**	**Combustion heat (MkJ· kg^{-1})**	**Calorific value qv.net.m (kJ· kg^{-1})**	**Air velocity ($m \cdot s^{-1}$)**	**Ambient tempera-ture (°C)**	**Measure-ment time (s)**	**The slope of the fuel reservoir (°)**
1.	8.1	20.36	17.39	0	12	255	0°a 25°
2.				0.5	12	130	0
3.				1	12	90	
4.				2.5	12	90	

Evaluation of the experiment

During the measurement, the progress of the fire was monitored, then the irregularities during the burning and unforeseen events (e.g. capturing of smoldering sample at the end of thermocouple, venting of the burning leaf from the wind tunnel and so on).

Monitored time parameters:

- a first measured time t_1, t_2, t_3, where it occurs to an initiation at the 1^{st}, 2^{nd} and 3^{rd} thermocouple,
- First measured time t_4, at which the flame front reaches the end of the fuel tank,
- Time t_5, in which all the fuel in the tank burns.

Monitored temperature parameters in three locations directly in the fuel sample:

- TER_1 - set temperature at a distance of 250 mm from the start of the reservoir on the first thermocouple,
- TER_2 - set the temperature at a distance of 500 mm from the start of the reservoir on the second thermocouple,
- TER_3 - set temperature at a distance of 750 mm from the start reservoir on the third thermocouple.

Parameters were determined from the experimentally obtained values:

- vp - linear speed of fire spreading ($mm \cdot s^{-1}$)
- Tmax - (T_{1max}, T_{2max}, T_{3max}) maximum temperatures occurring in the observed temperature profile (°C)

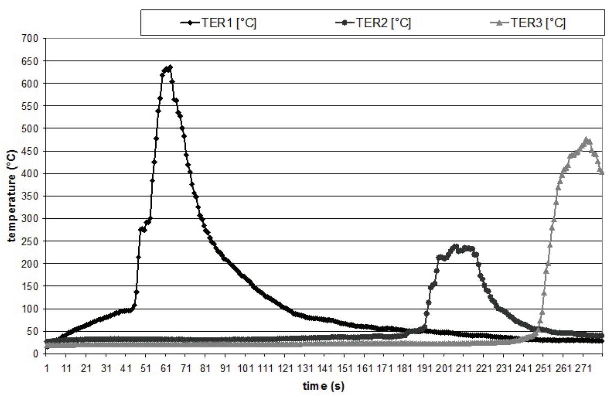
RESULTS AND DISCUSSION

The experimental results of our research present implement of laboratory models to simulate forest fire conditions. According STRIKLAND (2012) selected laboratory model of the fire is called the "head fire" that goes in the direction of the wind with just the right amount of fuel for the diffusion of the fire. The characteristic of that fire describes given action as a dynamic action at high temperatures. We based from the above characteristics also in a dealing with a model presenting a fire.

We obtained the values of the temperature curve according to time, the direct the sample burning in three different positions from the start of the reservoir, at the distance of 250, 500 and 750 mm by realization of a laboratory model of the forest fire.

Approximate experiments showed that in the above model, there is not possible to monitor the speed of flame spread in the simulation of inclined plane (at an inclination of reservoir). The inclination was to be able to simulate to a value of 25° only when the ventilator is switched off. It occurred to sliding of layers of litter and there was a blowing of samples in the case of increasing inclination.

The results of measurements simulating model of windless (Tab. 2) present the gradual spread of fire, shown in Fig. 2, where is quantitatively possible to monitor gradual increase of temperature in the thermocouples. As the subsequent decrease (as the result of transfer of the flame front). Significant movement of the increase of temperature (TER2) is important in the second thermocouple. It shows that the air flow is zero and the spread of the flame front is slower (150 s).



Legend: Abbreviation TER 1 presents the results of measurements on the first thermocouple, TER 2 presents the results of measurements on the second thermocouple and TER 3 presents the results of measurements on the third thermocouple.

Fig.2: Temperature curves for the 0 $m \cdot s^{-1}$ measurements.

We monitored the growth of temperature up to 50 seconds above 100° C in the framework of the above experiments after initiation and then temperature rapidly increased up over 600°C, successive decrease shows process of the flame front in the wind tunnel.

Results of experiments a laboratory model of the terrestrial forest fire with air velocity of 0.5m.s^{-1}

The experiments were carried out for 120, 150 and 130 seconds. The progress of the curves had a comparable character, average was made of these measurements (Fig. 3). In the initialization phase there is an increase of the flame front, which is in a time period between 20-30 seconds (Marková et al. 2012). The time lag of temperature increase (TER2) shortens on the second thermocouple with air velocity of 0.5 m·s^{-1} nearly about one-third (about 60 seconds).

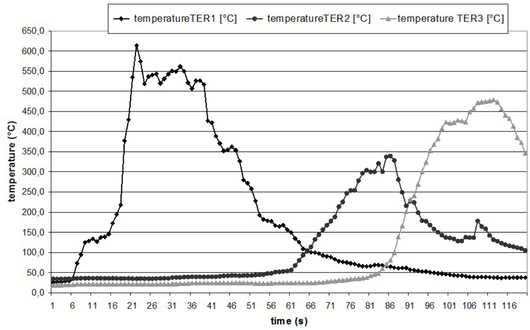


Fig. 3: Temperature curves for the 0.5 m·s^{-1} measurements.

Results of experiments a laboratory model of the terrestrial forest fire with air velocity 1.0 m·s^{-1}.

The experiments were carried out for 90 seconds. As it can be seen in Fig. 4, the progress of the temperature curves is different from the previous.

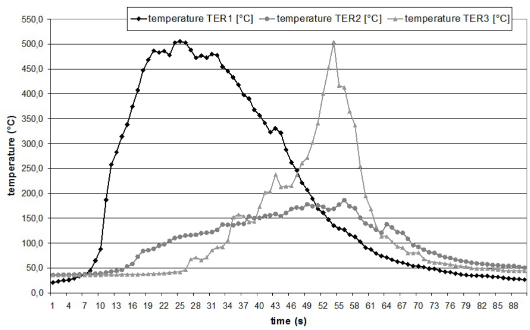


Fig. 4: Temperature curves for the 1.0 m·s^{-1} measurements.

Maximum temperature was achieved at the appropriate time difference in each thermocouple. Thermocouple TER 1 refers to a rapid increase of temperature during the initial 10 seconds, while there are maximum temperatures above 600°C Tab. 2). Thermocouple TER 2 refers to the temperature increase after 15 seconds and maximum temperature values reach lower values than TER 1 (Tab. 2). Third thermocouple recorded the temperature increase after 31 seconds. Calculated linear speed of fire spreading is 2.63 ± 0.10 cm·s^{-1}. It is incomparable with the experiment at air velocity of 0.5 m·s^{-1}.

Results of experiments a laboratory model of the terrestrial forest fire with air velocity 2.5 m·s^{-1}.

Realization of experiments was technically difficult. The experiments were carried out at 2.0 m·s^{-1}and the progress of the temperature curves is comparable to temperature curves with air velocity 2.0 m·s^{-1}. High velocity airflow caused venting of needles from around thermocouples and as a result of intensive air intake the slowdown has occurred after initiation in the front flame (Tab. 2).

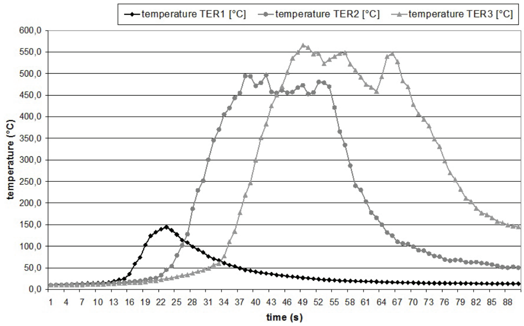


Fig. 5: Temperature curves for the 2.5 m.s^{-1} measurements.

Obtained progressions of temperatures were in the biggest variability. The progress of the temperature curves is different from the previous. TER2 monitored rapid increase in temperature in 19 seconds. The last initiatory time of temperature increase on TER3 was identical with the time of the experiment with air velocity of 1m·s^{-1}. Linear speed of fire spreading was calculated from measured data (Tab. 2).

Tab. 2: Results of experiments the laboratory model terrestrial forest fire.

Samples		**Parameter**								
Litter of black pine (*Pine negra*)	V (m·s^{-1})	t_1 (s)	t_2 (s)	t_3 (s)	t_4 (s)	t_5 (s)	T_{1max} (°C)	T_{2max} (°C)	T_{3max} (°C)	vp (cm·s^{-1})
	0	1-6	170	230	270	275	640	240	460	0.55
	0.5	1-6	60	80	133	170	618	285	520	0.76
	1.0	1-6	11	30	37	87	645	410	300	2.63
	2.5	15	29	29	38	79	559	263	550	2.67

With increased airflow increases the linear velocity of propagation of fire and reduces the time fire due to fast moving flame front (Fig. 6). (Fig. 7) for air velocity 1 m·s^{-1} and 2.5 m·s^{-1} are linear speed of fire spreading almost identical and it is expected that the said balance maintained. A key finding is the limit interval <0 - 1 m·s^{-1}>.

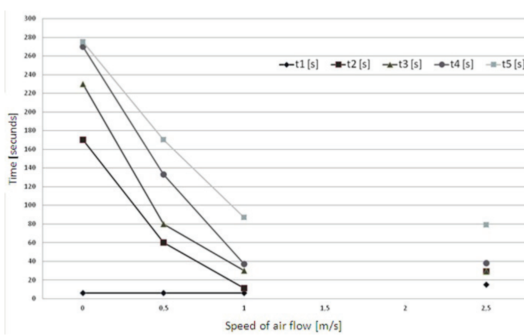


Fig. 6: Plot of thermal parameters for the selected air velocity within the model forest fire.

Speed of air flow of 1 m·s^{-1} becomes a critical value in the examination of the time of initiation. Where the time of initiation of the thermocouples is decreasing at 60% compared with zero value of air flow. There is decreasing time of initiation on the thermocouples of 30% with air velocity of 0.5 m·s^{-1}. However, it is subsequently retained with air velocity of 2.5 m·s^{-1} at the time of initiation on the thermocouples.

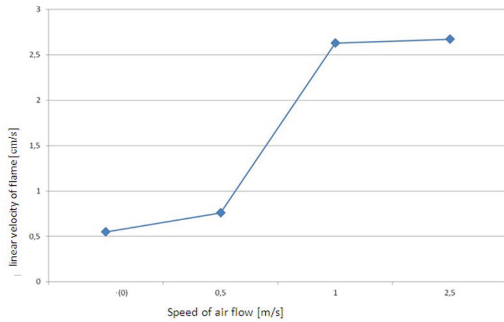


Fig. 7.Plot of linear velocity of flame spread for the selected air velocity within the model forest fire.

The result of comparing the speed of the airflow at a linear speed of fire spreading is the assumption that air velocity of 1 m·s^{-1}already (that is 3 km·s^{-1}) presents an increase of linear speed of fire spreading from 2 to 2.5 times compare to the air velocity 0.5m·s^{-1} (Fig. 8) and subsequently it is maintained. Air velocity of 2.5 m·s^{-1} (that is 9 km·h^{-1}) caused in laboratory model blowing of needles, also local preheating or interrupted burning was here.

We obtained an interesting result in quantifying the value of the linear velocity of spread, which is significantly comparable for models of the terrestrial forest fire with air velocity 1.0 cm·s^{-1} and 2.5 cm.s^{-1}. But time of fire spread has been reduced by 60% at specified speed from the time development of a fire at a speed of 0.5 cm·s^{-1}. Mentioned time factor has a priority role for the development of forest fires.

In 2005, Fitzgerald (2005) conducted a detailed analysis of the current state of pine ecosystem, namely Ponderosa pine in Montana and looking for risk of fire. Based on the classic triangle of combustion where the emphasis is also placed on the possibility of individual and thinning trees for purposes of limitation (elimination) of the spread of fire with the effect of increasing tree height with thinning crown. This also implies a reduction in the formation of the respective layers of litter. Lotan (1985) elaborated a comprehensive theory of the rotating forest fire to a pine forest, which highlights the environmental impact of dynamic change and the burning process in each cycle within the forest fire. The problem of forest fires was also concerned Landďák et al. (2012), which describes the development of forest fire under strong influence of external conditions and highlights the dominant airflow rate, which affects the development and intensity of the fire. Research velocities of forest fires shall be promoted through laboratory models and mathematical models (Fernandes 2014).

CONCLUSIONS

We can state facts based on an experiment:

1. In range < 0-1 m·s^{-1}> the time of ignition reduces gradually for each thermocouples
2. The result of experiments determines the air velocity 1 m·s^{-1} as sufficient to increase the

linear speed of fire spreading from 2 to 2.5 times compared to the air velocity of 0.5 $m \cdot s^{-1}$. The linear velocity of spread for models of terrestrial forest fire with air velocity 1 $cm \cdot s^{-1}$ and 2.5 $cm \cdot s^{-1}$ appeared significantly comparable. But time spread of fires at specified speed has been reduced by 60% from the time of fire development at a speed of 0.5 $cm \cdot s^{-1}$
3. there is no change in time of ignition from 1.0 $m \cdot s^{-1}$ due to increasing of air velocity in the wind tunnel
4. 2.5 $m \cdot s^{-1}$ air flow speed has been limit speed, which could be modeled in a wind tunnel
5. to quantify dependence between air velocity and linear velocity of spread of terrestrial forest fire

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