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Experimental investigation of the influence of geometry on gas accumulation using a V-shape forest model

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Abstract

Accumulation of gas inside a valley exposed to a light crosswind is experimented in this paper to evaluate the influence of gas in accelerating forest fire phenomena. Experimentations were done inside a wind tunnel using a 1/400 forest model configured as a valley with two different internal angles. The forest is modelled so that a parallel is possible with a real forest thanks to a similitude law. The emission of gas is ensured by 400 tubes introduced inside the mesh cylinders supplied with ethane. The 400 tubes are divided into four independent parts of 100 tubes to be able to study independently the influence of the different zones before and inside the valley on the accumulation of gases. We focused on the measurements of velocity by Laser-Doppler Velocimetry (LDV) and concentration with a Flame Ionization Detector (FID). Analyzing the velocity, turbulence and concentration results, we observed a stagnation point in the thalweg for the flattest valley and a recirculation zone for the deepest one where gas accumulation reached up to 4 times the concentration measured outside the valley. The study of the influence of the different emission zones showed that gas accumulation mainly comes from the zones inside the valley.

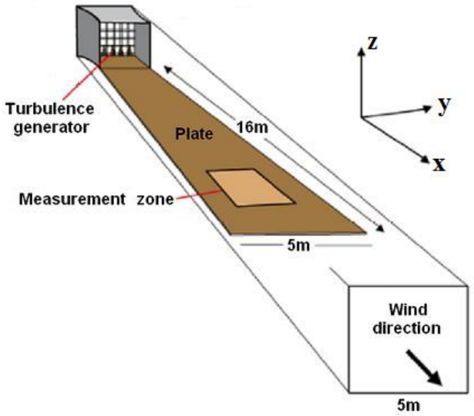
Keywords: *V-shape forest model; gas accumulation; gas emission; Laser-Doppler Velocimetry; concentration*

1. Introduction

During a forest fire, high concentrations of gases, which may come from fire smoke, pyrolysis products and emissions of vegetation (BVOCs), can be found inside a valley depending mainly on the meteorological conditions and the topography [1,2]. It is noteworthy that some experimented firefighters decide to run away from a forest fire when the surrounding odor is too strong and when the vision becomes hazy. This lets us think that a high concentration of gases is present at that moment. The problem encountered is the observation of Accelerating Forest Fires (AFFs) inside valleys or canyons. Indeed, numerous mortal accidents like those which happened in Mann Gulch (USA, 1949, 13 victims), La Gomera (Spain, 1984, 20 victims) or Kornati Island (Croatia, 2007, 11 victims) are described in the literature [1]. Initially, these AFFs appear to be classic forest fires but change unexpectedly their behavior with impressive rates of spread and heat releases letting behind them large burning areas. One of the possible causes of this phenomenon is the accumulation of gases in narrow areas like thalwegs or canyons with, in one hand, the fire smoke dispersed by complex air flow above and around the forest fire and, on the other hand, BVOCs and pyrolysis products emitted by heated plants because of the fire front radiation. The goal of this project is to have an idea of what happens inside a valley before the arrival of fire regarding the potential of accumulation of both smoke coming from above and BVOCs emitted inside the valley. To address these questions, we reproduced the spatial distribution of gas inside a valley (V-shaped) with a forest model exposed to a light crosswind. Experiments were performed to give information on the location of gas accumulation and whether or not it can be sufficient to form flammable gas pockets to catalyze the fire propagation. Some research studies have been done for street canyons to focus on the dispersion of pollutant [3,4] but, to our knowledge, there is no work on valley configuration with forest models.

2. Experimental section

Investigations were made in the wind tunnel "Lucien Malavard" of PRISME Laboratory, with a 1/400 forest model configured as a valley with varying angle in order to study the effect of geometry on the global air-flow. The wind tunnel has a 16 m-long rough development plate. Turbulence generators are fixed at the entrance of the test section to develop an atmospheric boundary-layer flow. The forest is modelled using 50 mm-high metallic mesh cylinders which are rolled up to their top to represent the higher leaf density of the tree crown. The cylinder arrangement was chosen to avoid any forced flow direction to the flow going through the canopy [5]. The biogenic emission coming from the forest canopy is represented by a surface source, which is modelled through a series of point sources of a passive tracer. The passive tracer is ethane, chosen for its density close to air. The release height is 40mm (80% of the tree height) and the distance between each point source is 50mm (tree height). Figure 1 illustrates a schematic overview of the wind tunnel and the modelled forest located in the measurement zone. The gas distribution comes from an ethane bottle linked to a first distribution device with which we can chose which of the four emission zones are active (Figure 2). This first distribution device is linked to four other ones built with enough pressure loss to permit an homogeneous surface source when the gas comes out from the tubes (Figure 3). Preliminary testing showed that, right above the canopy, the source was horizontally homogeneous. Consequently, the source is representative of a surface source. The emission zone of 400 tubes, is divided into four independent parts of 100 tubes (Figure 2). This allows us to study the effect of each zone of emission on the accumulation of gases inside the valley.



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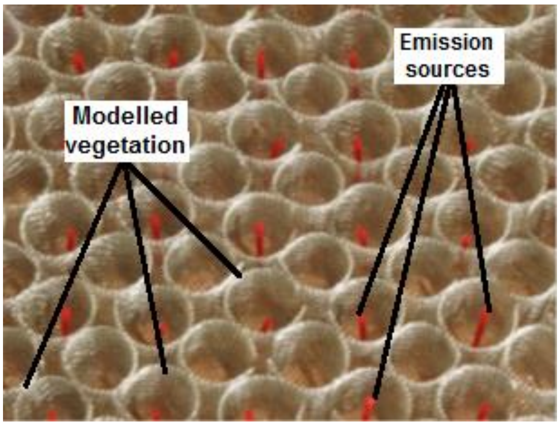

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Figure 1. Overview of the experimental setup of modelled forest in a wind tunnel: (a) Scheme of the wind tunnel; (b) Metallic mesh cylinders and ethane emission tubes (in red) constituting the model placed in the measurement zone.

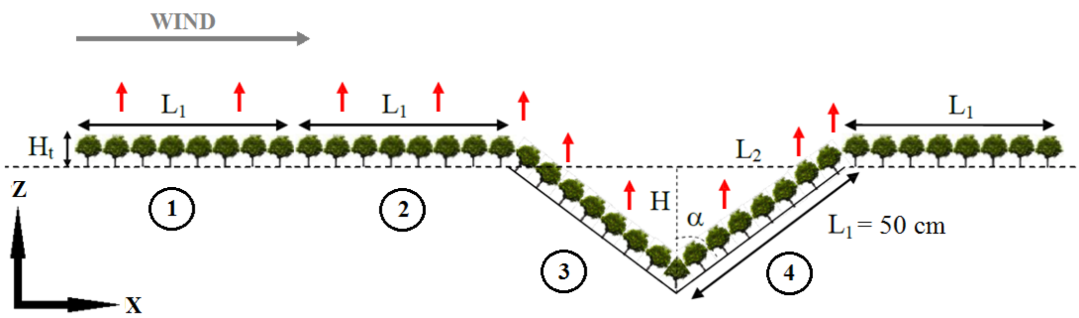

Figure 2. Simplified 2D scheme of the forest model and the four zones of ethane emission, zone 3 is called the lee side and zone 4 the wind side

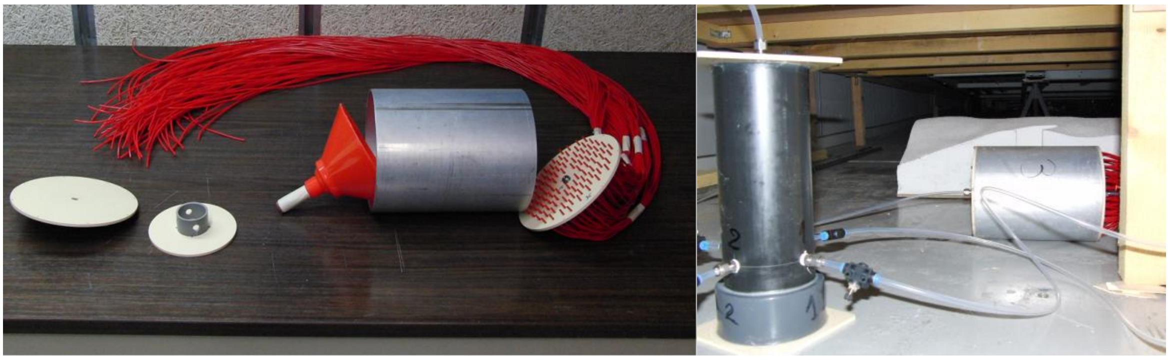

Figure 3. The two photographs depict the distribution device of ethane placed under the model

Experimentations in the wind tunnel gather two types of measurements above the canopy of the four zones: measurements of velocity with a Laser-Doppler Velocimetry (LDV) and measurements of concentration with Flame Ionization Detector (FID) (Figure 4).

Figure 4. LDV on the left and FID on the right above the V-shaped forest model

For the velocity measurements by LDV, the flow was seeded with olive oil micro-particles upstream of the turbulence generators. By referring to Viegas's work [6], we have chosen two different half internal angles of valley α = 50° and α = 80° (Figure 3). The forest model permits then to make a parallel with a real forest thanks to a similitude law [5]. Indeed, the measured concentrations will be given at reduced scale in a dimensionless form (Eq.1) in order to extrapolate them to full scale situations using real parameters (Eq.2):

$$c^* = \frac{c[m^3/m^3_{mix}] \times U_{ref}[m/s]}{Q_{source}[m^3/s/m^2]} \qquad (1)$$

$$c_{full\ scale} = f\left(x, z, c^*, U_{ref}, Q_{source}, \alpha, H_t\right) \qquad (2)$$

3. Results

3.1. Velocity

From our different experiments, we measured velocity, turbulence and concentration obtaining grids of values above and inside the valley for the two different angle configurations. To normalize our measurements, we divided them by a reference speed located before the forest at ten times the canopy height. Analyzing the results with the velocity streamlines we observe on the left of Figure 5 below that there is no recirculation with the flattest valley even if we have a potential of accumulation in the thalweg where the horizontal component of the velocity (U) is almost null. On the right of Figure 5, we observe clearly a clockwise recirculation for the deepest valley. Regarding the turbulence intensity with the Figure 6, we notice that it is located above the canopy for the flat part of the forest and that it increases a lot above the valley with the detachment of the boundary layer. For the 80° angle, the turbulence intensity inside the valley is multiplied by four if we compare it to the flat forest, with a maximum of 1.4%. Turbulence intensity is much stronger for the 50° angle, and reaches up 76% above the valley (Figure 6 and 7) even if there is not so much turbulence near the thalweg. Thus, gas accumulation is possible in this place.

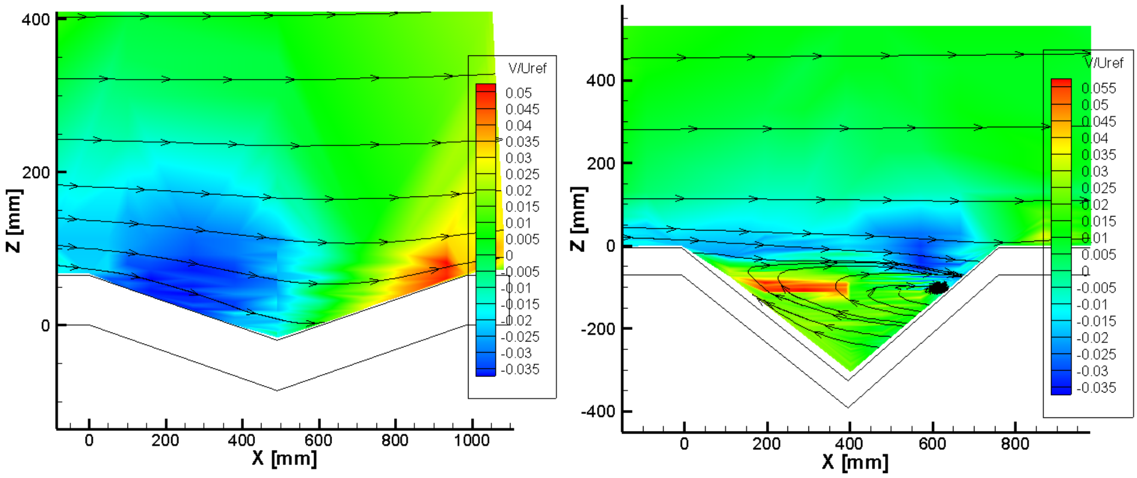

Figure 5. Vertical component of the velocity (V) normalized by Uref with streamlines of the velocity, for α = 80°on the left and α = 50° on the right

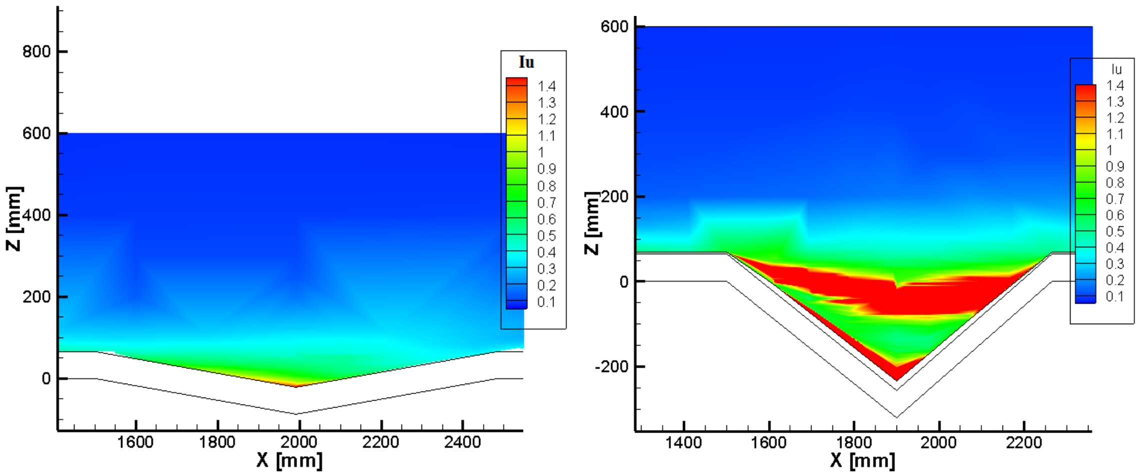

Figure 6. Turbulence intensity on U for α = 80° on the left and α = 50° on the right

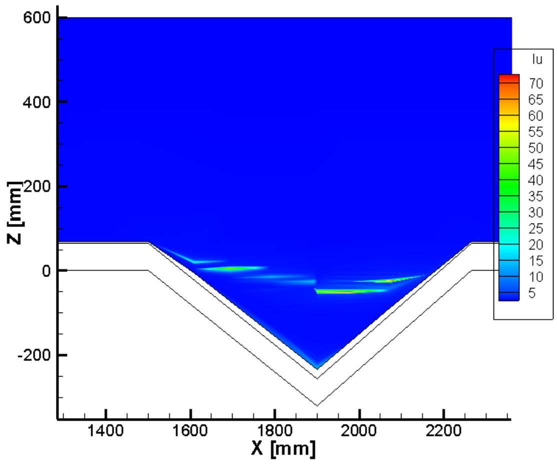

Figure 7. Turbulence intensity on U for α = 50°

3.2. Concentration

If we look now at both concentration and velocity, we obtain the Figure 8 below for 80° and 50°. We notice at 80° that accumulation is located in the thalweg due to the weak velocity in this zone. The maximum concentration is measured at 980 ppm almost twice the concentration measured above a flat forest. At 50°, an accumulation of gas is visible above the lee side due to the recirculation. We reach up a maximum of 1790 ppm increasing the concentration by more than 3.5 times if we still compare to the flat forest.

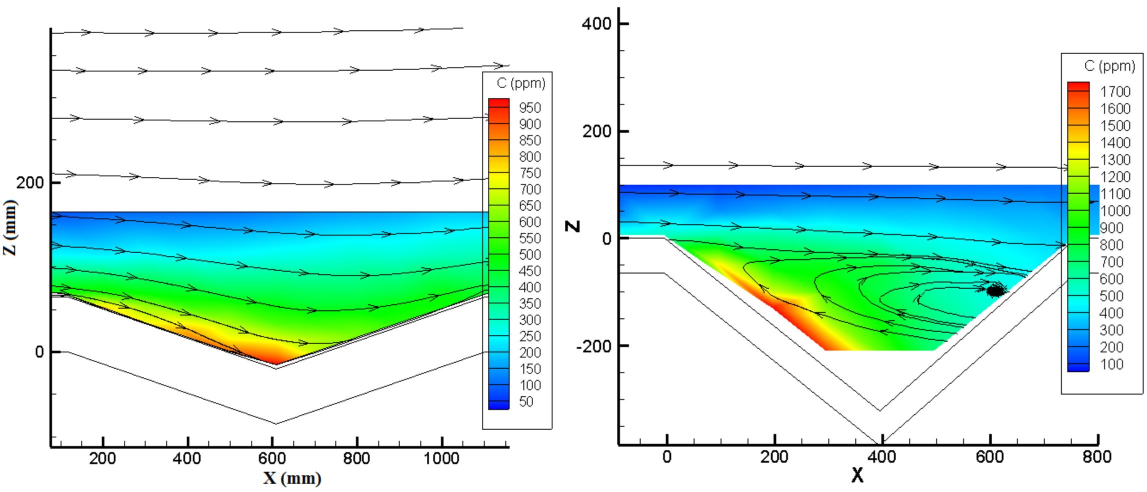

Figure 8. Concentration with velocity streamlines for α = 80° on the right and for α = 50° on the left

3.3. Footprint of the different forest model zones

The following experiments were carried out to know the footprint of the different zones, to know which zones of the forest model are more influent on the gas accumulation. To this end we plugged and unplugged the different emission zones from the distributor. Figure 9 below presents the concentration with all zones emitting on the left graph and only zone 3 on the right. To compare the results we normalized the concentration following the equation 1 page 4. With the 80° angle, we concluded that the inlet part (zone 1 and 2) does not influence the accumulation inside the valley. Focusing on the angle 50° (Figure 9) with the recirculation zone, we observed that it is mainly the lee side (zone 3) which influences the accumulation with a maximum at C* = 152 whereas with all zones emitting we obtained a maximum of C* = 194. This maximal accumulation is located just above the canopy at the middle of the lee side. Letting now only the wind side emitting (zone 4), we have a maximal accumulation located in the thalweg with a maximal normalized concentration found at 79.

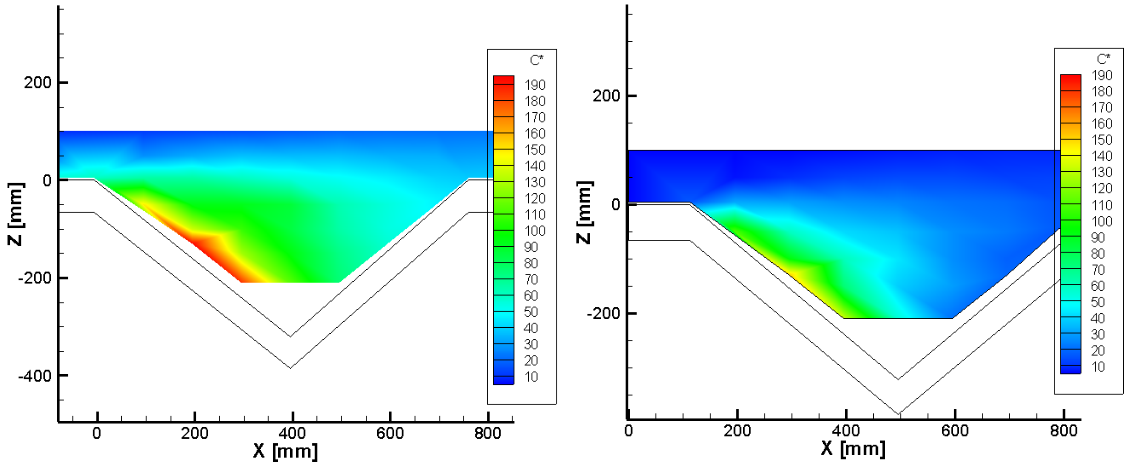

Figure 9. Normalized Concentration all zones emitting on the left and lee side only on the right for 50°

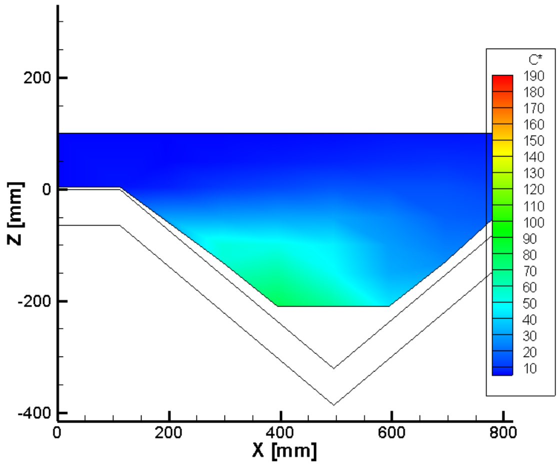

Figure 10. Concentration (ppm) of only wind side emitting for 50°

3.4. Extrapolation to real case

Knowing the influence of each zone, we observe that the risk of accumulation is present if there are emissions from the inside the valley with heated vegetation for example. With the arrival of the fire it is the wind side which will be directly exposed to the radiation and will emit more than the lee side. We could then imagine adding coefficients for each zone to analyze a real case. By plotting the normalized concentration, we see that concentration just above the canopy is multiplied by 3.5 to 4 inside the valley.

Studies of BVOC emissions from real forests evaluate the emission at about 1 $g/m^2.h$ in favorable regions (dry summers and wooded areas) [7]. Since 50% of emissions are released in July and August, emissions grow to 3 $g/m^2.h$ during this period. Knowing that *Rosmarinus officinalis*, one of the Mediterranean plant species involved in AFFs, emits eight times more at 175°C than at 50°C [8], we can estimate emissions superior than 24 $g/m^2.h$ when a forest fire is approaching heating the vegetation with radiation. If we consider now that vegetation is heated during one hour then we have emissions of 24 g/m^2. If we hypothesize that there are not so much air flow and that emissions are dispersed in 100 m^3. Thus we can evaluate that VOC emissions can reach 0.24 g/m^3 near a forest fire. Then we know that if these VOCs are emitted near a narrow valley, they can accumulate up to 4 times to get around 1 g/m^3. Studies show that VOCs like α-pinene have a lower flammability limit (LFL) around 1% volumetric [2,9]. According to the density of air and α-pinene we obtain around 0.6% which is rather close to the LFL. Knowing that there are many approximations, the chance of being in presence of a flammable atmosphere inside a narrow valley is still imaginable.

4. Conclusion

We analyzed velocity, turbulence and concentration results for two different half internal angles of a valley model. Velocity permitted us to observe a potential of accumulation in the thalweg where the velocity is almost null for $\alpha = 80°$. For $\alpha = 50°$, we highlighted a recirculation zone inside the valley. Analyses of the turbulence showed that there could be an accumulation of gas in the thalweg of the 50° angle where turbulence is lower than above. By measuring the concentrations, we observed an accumulation in the valley up to twice more than a flat forest for $\alpha = 80°$ and up to four times more for $\alpha = 50°$. The study of the zone footprint permitted us to say that emissions outside the valley do not have an impact of accumulation inside the valley in our case. Focusing on the 50° angle and studying the emissions of lee side (zone 3) and the wind side (zone 4) independently, we concluded that these are mainly the emissions of the lee side which influence the gas accumulation. Due to the recirculation, gas accumulation is located just above the canopy in the middle of the lee side. Emissions from the wind side accumulate in the thalweg. Numerical study with a Computational Fluid Dynamics code could permit to obtain further results varying the angle (α) with which we could obtain, for example, the threshold of the angle not to overcome to stay in safe concentration, below the LFL of VOCs. The fact that concentration inside the valley is four times the one measured for a flat forest shows that LFL is not so far and that the hypothesis of gas accumulation is still relevant.

5. References

[1] D.X. Viegas, A. Simeoni, Eruptive behaviour of forest fires, *Fire Technology*, vol. 47, pp. 303-320, 2011.

[2] F. Gerdes and D. Olivari, Analysis of pollutant dispersion in an urban street canyon, *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 82, pp. 105-124, 1999.

[3] M. Pavageau, M. Schatzmann, Wind tunnel measurements of concentration fluctuations in an urban street canyon, *Atmospheric Environment*, vol. 33 pp. 3961-3971, 1999.

[4] K. Chetehouna, L. Courty, J.P. Garo, D.X. Viegas, C. Fernandez-Pello, Flammability limits of biogenic volatile organic compounds emitted by fire-heated vegetation (Rosmarinus officinalis) and their potential link with accelerating forest fires in canyons: A Froude-scaling approach, *Journal of Fire Sciences*, In press, 2014, doi: 10.1177/0734904113514810.

[5] S. Aubrun, B. Leitl, Development of an improved physical modelling of a forest area in a wind tunnel, *Atmospheric Environment*, vol. 38, pp. 2797-2801, 2004.

[6] D. X. Viegas, A mathematical model for forest fires blowup, *Combustion Science and Technology*, vol. 177, pp. 27-51, 2005.

[7] V. Simon, L. Luchetta, L. TorresEstimating the emission of volatile organic compounds (VOC) from the French forest ecosystem, *Atmospheric Environment*, Volume 35, pp. 115-126, 2001.

[8] K. Chetehouna, T. Barboni, I. Zarguili, Leoni A. Simeoni. And A. C. Fernandez-Pello. Investigation On The Emission Of Volatile Organic Compounds From Heated Vegetation And Their Potential To Cause An Accelerating Forest Fire, *Combustion Science and Technology*, Volume 181, Issue 10 (2009)

[9] L. Catoire, V. Naudet, Estimation of temperature-dependent lower flammability limit of pure organic compounds in air at atmospheric pressure, *Process Safety Progress* 24 (2005) 130-137.