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Investigation of firebrand production from Douglas-Fir

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Abstract

Firebrands are one of the leading mechanisms of spread during wildfire and WUI fires, where hot firebrands can be transported several kilometers ahead of the fire front, potentially creating new fires. Thus, a better understanding of the parameters affecting firebrand generation and characteristics is mandatory to develop better simulation models and predict the "firebrand potential" of different species. The goal of this study is to create a test procedure to characterize the firebrand generation efficiently and to analyze the reproducibility and relevance of the results. The experiments were conducted inside an 11m-long wind tunnel with two variable speed fans. Trunks and branches from Douglas-Fir (*Pseudotsuga menziesii*) samples were dried and tested separately using a 30cm-by-30cm propane burner under wind velocities that ranged from 0.4 m/s to 2.0 m/s. For each experiment, the firebrands generated were collected using water-filled pans with fine meshes inside. The mass distribution of the firebrands over the test section was measured using a load cell. It was observed that the heaviest firebrands only reach the pans next to the tree. Moreover, these pans contained most firebrands produced during the experiments. Thus, at low wind velocity (0.4 m/s), the wind is not strong enough to propagate the firebrands on a large area.

1. Introduction

Firebrands are primarily generated from burning wildland fuels (trees, shrubs, branches) and wooden structures (roofs, structural members). They are produced when the burning fuel thermally decomposes, loses structural integrity, and breaks down into smaller burning portions (Cohen & Deeming, 1985). These smaller portions will eventually separate from the main structure due to the drag forces generated by the airflow surrounding the burning element. Then, they will be lofted in the air by the fire-induced buoyant plume in a flaming or smoldering state (Sánchez Tarifa et al., 1965).

Several parameters have an impact on the geometric characteristics of the firebrands such as the fire behavior, the characteristics of the fuel and the environmental conditions (Bahrani, 2020). Furthermore, the ignition-by-firebrand potential depends on the number of firebrands landing in the same area, the thermal properties of the recipient fuel (moisture content, thermal inertia, density) and the properties of the firebrands (temperature, area, mass) (Cohen & Deeming, 1985).

This work presents the preliminary results of a series of experiments focused on studying the generation of firebrands from 1 m tall Douglas-fir (Pseudotsuga menziesii) samples as a function of wind velocity and for a set fire exposure in the controlled setting of a large-scale wind tunnel. First, a description of the experimental design will be given. Then, the different test parameters and the test matrix will be presented. Finally, the results of the preliminary experiments, including the mass distribution and the characterization of the firebrands, will be presented.

2. Experimental design

2.1. Experimental setup

The wind tunnel used in these experiments comprises a conditioning section, a test section, and a discharge section. The structure of the wind tunnel is shown in Fig. 1.

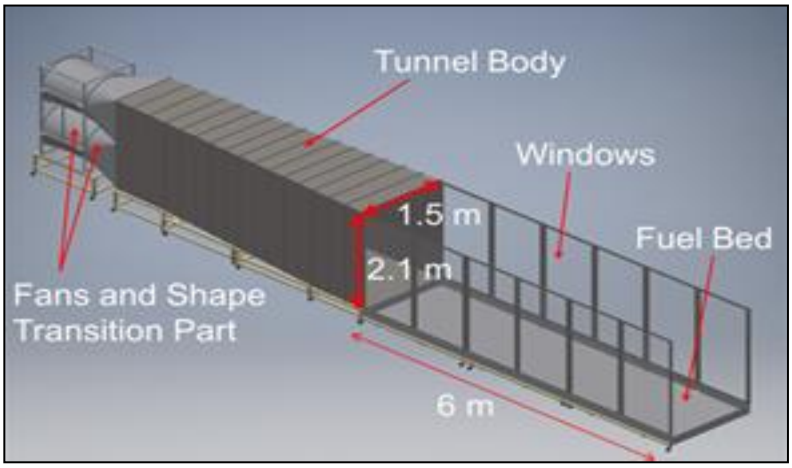


Fig.1: Schematic of the wind tunnel

In the conditioning section, two variable speed fans, along with the diffuser and straighteners, provide a stable and well-characterized inflow at the inlet of the test section.

The 6 m long test section is attached to the exit of the conditioning section and has a cross-sectional area of 1.5 m (width) by 2 m (height). It is equipped with tempered windows for flow and flame diagnostics. Within the test section, a 1.5 m width by 6 m long test bed is placed.

At the beginning of the test bed, a 30cm-by-30cm propane burner was installed. The heat release rate (HRR) of the burner is set by a mass flow controller regulating the volumetric flow of propane being delivered. The size of the burner was selected based on the maximum diameter of the samples used to ensure complete flame engulfment and avoid edge effects over the sample, as shown in Fig. 2a.

Downstream from the burner, the vegetation sample is mounted over a 60cm-by-45cm platform and held in place with a steel bracket, as shown in Fig. 2b. A 0.2 g sensitivity scale sampling at 1 Hz is placed below the platform to record the mass loss of the sample during testing.

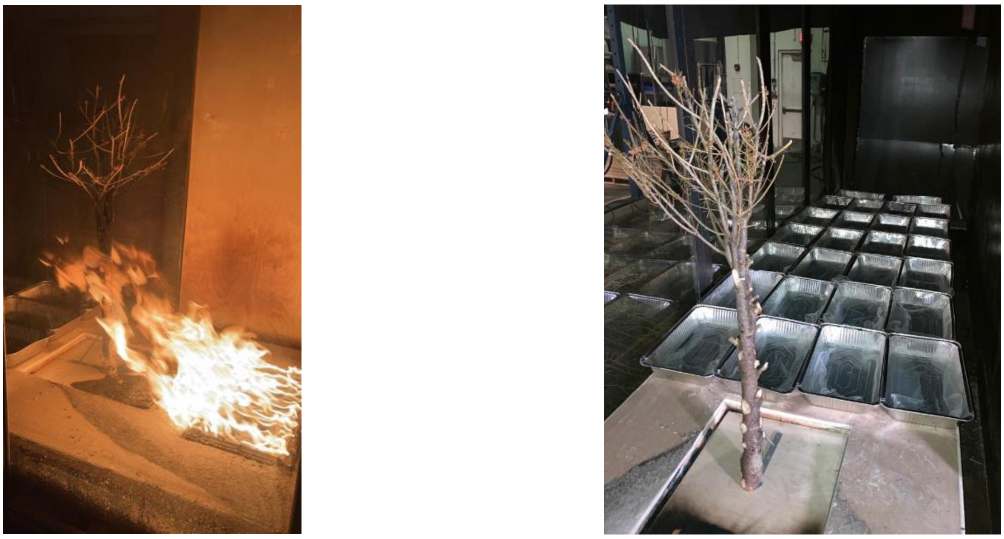
To collect the firebrands, a layout of aluminum pans of 53cm-by-33cm was placed on the test section downstream from the sample (Fig. 2b). These pans were filled with water to extinguish the firebrands when they landed. A fine mesh (0.6mm-by-0.6mm grid size) was placed below the water level to collect the firebrands inside the pan after each experiment.

At the discharge section, a deflector is placed to prevent the firebrands from escaping the confined test environment.

Two cameras were used to record the experiments and to track the firebrands:

- A high-speed camera on the side of the tunnel facing the glass panels was used to track the firebrands throughout the test section. The data collected from this camera allowed for estimating firebrand velocities during flight.
- A GoPro camera placed close to the fuel sample, behind the glass panels, was used to record its ignition at the beginning of the experiments

After each experiment, the firebrands were collected, dried, and weighted using a 0.01g-accurate load cell to determine the mass distribution.



(a) (b)

Fig. 2: Testbed. (a) Propane burner. (b) Mounting platform and aluminum pan array used to collect the firebrands generated

2.2. Fuel selection

For the current study, Douglas-Fir (*Pseudotsuga menziesii*) samples were used. The species was selected due to its geographical accessibility and the availability of data and results from the literature (Manzello et al., 2006; Baker, 2011; Manzello et al., 2008).

The moisture content inside vegetative fuels significantly impacts the fire behavior and the firebrand generation. A quantitative analysis of the effect of the different moisture content of vegetative fuels is given in (Manzello et al., 2008). Three different levels can be found (mass basis); With a moisture content of 70% or above, no sustained burning after the ignition will be observed, and thus no firebrand generation. When the moisture content is between 30% and 70%, a transition regime occurs where the tree will be partially burned after the ignition. For moisture content below 30%, the tree will be entirely consumed after the ignition and firebrand generation will occur. Moreover, Douglas-Fir will not produce firebrands if its moisture content exceeds 30% (mass basis) (Baker, 2011).

Thus, a fuel conditioning chamber was built to reduce the moisture content of the vegetative fuels used for the experiments. This chamber will also allow us to dry the wet firebrands after the experiments to then characterize and analyze them. An operational temperature of 61°C was achieved inside the chamber.

The samples were prepared from locally sourced two-meter-tall live trees as follows:

First, the branches were separated from the trunks and stacked in different packages. Then, the trunks were cut in half to fit inside the test section, labeled, and placed in the drying chamber. The moisture content and the weight of each trunk were checked every day to follow the evolution of the drying procedure.

Before testing, the moisture content was determined using a wood moisture meter able to measure the moisture content (volume basis) between 1.5% and 50 % with a +/- 2% accuracy. Through the drying procedure described above, the samples achieved a moisture content of 15% before testing.

2.3. Experimental matrix

Preliminary experiments were conducted to determine the most suitable HRR and wind velocities inside the tunnel. The different wind velocities selected are shown in Table 1. A HRR of 300 kW/m^2 was selected as it was the minimum HRR to achieve sufficient flame engulfment given the characteristics of the burner and the rest of the experimental setup.

The branches and the trunks were tested separately to see the difference in terms of firebrand production with the same parameters.

Table 1: Experimental matrix.

Fuel Type	Wind velocity (m/s)	HRR (kW/m^2)	Repetitions
Trunk	0.4	300	3
	1.0		3
	2.0		3
Branches	0.4	300	3
	1.0		3
	2.0		3

3. Results

In the following section, the preliminary results of some experiments conducted using tree trunk samples are presented to illustrate the approach in practice. These experiments were conducted at a 0.4 m/s wind velocity and 300 kW/m^2 HRR.

3.1. Weight distribution

The primary trend observed in the mass distribution is that the heaviest firebrands only reach the first row of pans. Figure 3 shows the weight distribution of the firebrands under a 0.4 m/s wind velocity. Because of the low velocity, none of the firebrands generated reached the pans furthest from the fuel sample. Further experiments using higher wind velocities are required to determine the impact of the wind on the distance traveled and the mass distribution of the firebrands.

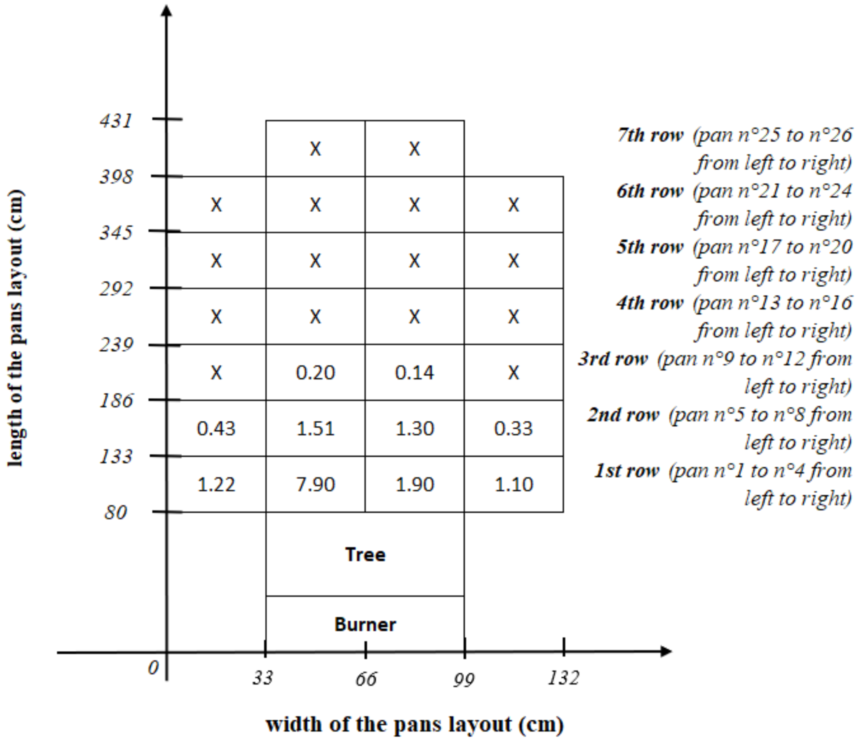


Fig. 3: Weight distribution of the firebrands for a preliminary test

3.2. Characterization of the firebrands generated

After each experiment, the meshes containing the firebrands were removed from the pans and dried for two hours. Pictures from two different pans are shown in Fig. 4a and Fig. 4b.

The primary trend observed during the preliminary experiments is that the number of firebrands per pan and their size decreases when the distance from the tree increases. Moreover, for the same row, the pans placed on the sides of the test section will receive fewer and smaller firebrands than the pans placed in the middle.

(a) (b)

Fig. 4: Firebrands collected at different locations during preliminary experiments with a 0.4 m/s wind velocity. (a) Firebrands collected in the first row (pan n°2). (b) Firebrands collected in the second row (pan n°5).

3.3. Firebrand velocity

From Figure 5, it can be seen that the absolute velocity of the firebrands correlates well with the imposed wind velocity. The variation in the range of velocities measured is attributed to the variation in mass and geometry of the firebrands collected. Both parameters will alter the contribution of buoyancy and aerodynamic drag over the firebrands. As mentioned earlier, further experiments are required to analyze the influence of wind velocity over the absolute velocity of the firebrands generated.

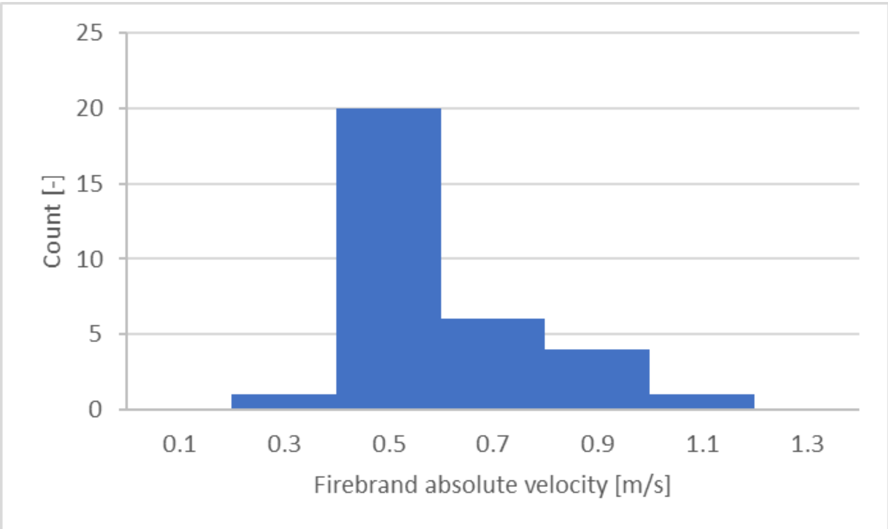


Figure 5: Aggregated firebrand velocity distribution for an experiment conducted using a flow velocity of 0.4 m/s.

4. Conclusion

A series of experiments were conducted using Douglas-fir under different wind conditions to analyze the firebrands' characteristics and mass distribution as a function of fuel type and crossflow velocity.

The preliminary results presented here demonstrate the methodology under which the study is conducted. The complete version of the study will showcase a detailed analysis of the results obtained for the complete experimental matrix proposed.

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