ON THE IGNITION OF FUEL BEDS BY FIREBRANDS[1]

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ABSTRACT

An experimental apparatus has been built to investigate the ignition of fuel beds as a result of impact with burning firebrands. The apparatus allowed for the ignition and deposition of both single and multiple firebrands onto the target fuel bed. The moisture content of the fuel beds used was varied and the test fuels considered were pine needle beds. Firebrands were simulated by machining wood into small disks of uniform geometry and the size of the disks was varied. The firebrand ignition apparatus was installed into the Fire Emulator / Detector Evaluator (FE/DE) to investigate the influence of an air flow on the ignition propensity of fuel beds. Results of this study are presented and compared to relevant studies in the literature.

INTRODUCTION

Urban-wildland fires have plagued the United States for centuries (Cohen, 1991; Pagni, 1993). The devastation caused by these fires is massive; the Hayman Fire in Colorado burned 137,000 acres and destroyed over 600 structures. As a consequence, fires in the urban-wildland interface can have a devastating effect on human life, property loss, and local economies.

Firebrands or embers are produced as trees and other objects burn in urban-wildland fires. These firebrands are entrained in the atmosphere and may be carried by winds over long distances. Hot firebrands ultimately come to rest and may ignite fuel beds far removed from the fire, resulting in fire spread. This process is commonly referred to as spotting. Understanding how these hot firebrands can ignite surrounding fuel beds is an important consideration in mitigating fire spread in communities.

It is believed that pine needles in the gutters of homes are susceptible to ignition by firebrand showers (Cohen, 1991). Unfortunately, ignition due to spotting is one of the most difficult aspects to understand in these fires (Babrauskas, 2003). Consequently, the ignition of fuels due to firebrand impact has been investigated, but a limited number of laboratory studies are available in the open literature (Babrauskas, 2003).

OBJECTIVES

The goal of this study is to understand how lofted firebrands created by urban-wildland fires ignite the impacted fuel bed. To this end, this paper describes an apparatus that has been constructed to investigate the ignition propensity of the materials due to the impingement of firebrands. The apparatus allowed for the ignition and deposition of single and multiple firebrands onto a target fuel bed. The ability to deposit multiple firebrands onto a target fuel bed is important, as most homes and other structures are bombarded by firebrand showers in urban-wildland interface fires. The moisture content of the fuel beds used was varied and the test fuel beds considered were pine needle beds. Pine needle beds were intended to simulate gutters filled with pine needles. The apparatus was designed to be implemented into the Fire Emulator / Detector Evaluator (FE/DE). The Fire Emulator / Detector Evaluator, or FE/DE, was used here as a wind tunnel to investigate the influence of an air flow on the ignitability of fuel beds.

METHODS

Figure 1 is a schematic of the experimental apparatus used for the firebrand impact studies. The firebrand ignition apparatus consists of four butane burners and a firebrand mounting probe. The butane flow rate is controlled by a metering valve coupled to a solenoid valve. The firebrand, or in the case of multiple firebrand impact, firebrands, are held into position and the air pressure is activated, which moves the actuator and clamps the firebrand(s) into position.

The motion of butane burners is displayed in figure 1. The butane torches are mounted on a sliding bracket that is coupled to a linear actuator. After the firebrands are mounted, the spark is activated and the fuel solenoid is opened. The butane burners are ignited and through the use of another linear actuator, the entire assembly is moved into position under the firebrand(s). The retraction of the burner upon ignition and the free-burn time of the firebrands are computer controlled which ensures repeatability. Each butane burner was designed to be switched on or off, depending upon the number of firebrands needed for the particular experiment.

As mentioned, the experimental apparatus was designed to simultaneously release and deposit multiple firebrands. It was important to space each firebrand carefully when performing multiple firebrand ignition studies. The reason for this is that it was desired to simulate the flux of multiple firebrands onto a fuel bed. If the firebrands were aligned too closely, they would not burn in the space between each firebrand. As a result, under such conditions, it was not possible to produce glowing firebrands. Therefore, a series of brass spacers were used to hold the firebrands in place. Up to 4 firebrands were loaded into the firebrand ignition apparatus. Further details of the apparatus are given elsewhere (Manzello *et al*., 2004; Manzello *et al*., 2005a,b)

The firebrand ignition apparatus was installed in the duct of the FE/DE. The FE/DE is described elsewhere (Grosshandler, 1997; Cleary *et al*., 2000) and was used here as an air flow source for the experiments. The FE / DE allowed for air flow rates up to 3 m/s and these velocities were verified through laser doppler velocimetry (LDV) measurements.

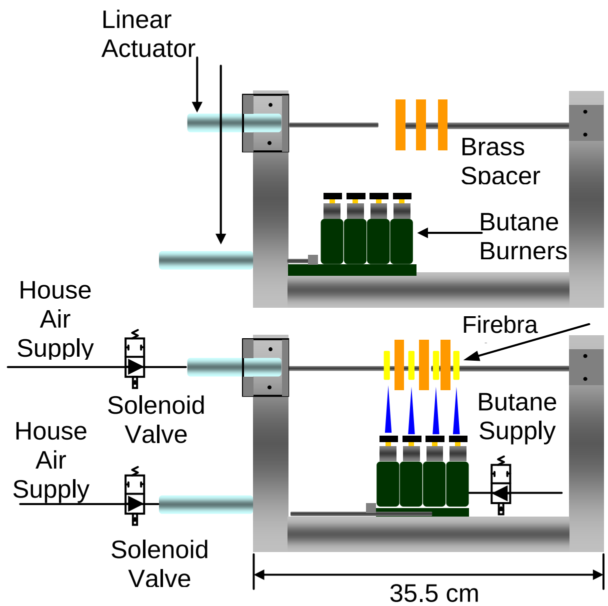

Fig. 1 Schematic of the firebrand ignition and release apparatus.

Firebrands were simulated by machining wood into sections of uniform geometry. Firebrand simulation was necessary since it is difficult to capture firebrands from burning objects (Waterman and Takata, 1969). An important consideration in simulating firebrands is the size and shape (Tarifa *et al*., 1967; Woycheese, 2001). Both the size and shape are important factors as it is these properties that determine the lofting characteristics and burn time of the firebrands.

For the present study, firebrands were simulated as disks of two different sizes. The first size produced was 25 mm in diameter with a thickness of 8 mm. The second size used was 50 mm in diameter and 6 mm thick. Disks are believed to be a representative shape that can easily be generated in urban-wildland fires (Woycheese, 2001). In addition, disks of this size range are capable of being lofted over long distances (Woycheese, 2001)

Ponderosa Pine (*pinus ponderosa*) was selected as the wood type for these experiments since it is abundant in the Western United States and it is here that urban-wildland fires are most prevalent. Prior to machining the disks, the ponderosa pine planks were stored in a conditioning room at 21 °C, 50 % relative humidity. After the disks were machined, they were stored in the conditioning room prior to the experiments.

Pine needle beds were used as test fuel beds for the ignition experiments. The impact of burning firebrands on pine needle beds was designed to simulate the showering of firebrands into gutters. The pine needles were contained in aluminum foil pans of 23 cm long by 23 cm wide by 5.1 cm deep. The moisture was varied from 0 % to 11 %. The moisture content was determined by oven drying the samples. It was found that three hours of oven drying at 104 °C was sufficient to remove all the moisture in the pine needle beds.

The firebrand ignition process and release onto the target fuel beds was captured using a CCD camera coupled to a zoom lens. In addition, high resolution digital still photography (2084 by 1024 pixel resolution) was used to capture the ignition of the target fuel bed due to firebrand impact.

RESULTS AND DISCUSSION

The firebrands were released onto the target fuel beds in both a flaming state and a glowing state. It has been suggested that firebrands fall at or near their terminal settling velocity. As such, when firebrands contact ignitable fuel beds, they are *most likely* in a state of glowing combustion, not open flaming (Waterman and Takata, 1969; Tarifa *et al*., 1967). It is possible for firebrands to remain in a flaming state under an air flow and therefore it is reasonable to assume that some firebrands may still be flaming upon impact. As a result, the ignition propensity of the pine needle beds was assessed based upon *both* glowing and flaming firebrand impact.

Experiments were performed for single firebrand impact (both flaming and glowing) to investigate whether it was possible to ignite fuel beds under such conditions. Figure 2 displays characteristic images of glowing firebrands which were released onto the pine needle beds. The results obtained for single glowing firebrand impact into pine needle beds is displayed in table 1. Each result was based on identical, five repeat experiments. The acronym NI denotes no ignition. For the firebrand sizes tested and the experimental combination tested, it was not possible to ignite pine needle beds from single glowing firebrand impact. After the firebrand impacted the pine needle bed, one or two needles would smolder and the smolder front would not propagate further in the bed.

Fig. 2 (a) Glowing firebrand, d_0 = 25 mm (b) Glowing firebrand, d_0 = 50 mm.

Table 2 displays the results for single flaming firebrand impact onto pine needle beds. To produce flaming firebrands, the firebrands were ignited and then allowed to free burn for 30 s prior to release into the samples. The acronym FI denotes flaming ignition. From these tables, under all conditions considered, it was possible to produce flaming ignition for single firebrand impact when the firebrands were released in a flaming state onto pine needle beds. These results suggest that if the firebrands are in flaming mode, only a single firebrand is required to begin an ignition event for these materials. The ignition process due to a single flaming firebrand impacting a pine needle bed is shown in figure 3.

Table 1 Glowing firebrand ignition data for single firebrand impact into pine needle beds.

Ember Size (mm)	Pine Needles (dry)	Pine Needles (11 %)
25	NI	NI
50	NI	NI

0.5 m/s

Ember Size (mm)	Pine Needles (dry)	Pine Needles (11 %)
25	NI	NI
50	NI	NI

1.0 m/s

Fig. 3 Single flaming firebrand which produced flaming ignition in a pine needle bed held at 11% moisture, d_0 = 25 mm.

Table 2 Flaming firebrand ignition data for single firebrand impact into pine needle beds.

Ember Size (mm	Pine Needles (dry)	Pine Needles (11 %)
25	FI	FI
50	FI	FI

0.5 m/s

Ember Size (mm	Pine Needles (dry)	Pine Needles (11 %)
25	FI	FI
50	FI	FI

1.0 m/s

The results obtained for the pine needle beds suggest that a shower of glowing firebrands is required to ignite pine needle beds. Therefore, based upon these findings, the flux of firebrands is clearly an important parameter which must be considered.

Consequently, the experiments were repeated, but now multiple firebrands were deposited upon the pine needle beds. Single flaming firebrands were able to ignite pine needle beds, thus multiple flaming firebrand experiments were not conducted for these materials.

Table 3 displays results obtained for multiple glowing firebrand impact upon pine needle beds. From the table, the deposition of four 25 mm glowing firebrands did not produce an ignition event under the conditions tested. For the 50 mm glowing firebrands, smoldering ignition was observed to occur when four firebrands were deposited on pine needle beds under an air flow of 1.0 m/s. Under an air flow of 0.5 m/s, 50 mm glowing firebrands did not produce an ignition. When four 50 mm firebrands were deposited upon pine needle beds, smoldering was observed followed by a transition to flaming combustion under an air flow of 1.0 m/s.

Table 3 Glowing firebrand ignition data for multiple firebrand impact upon pine needle beds.

Ember Size (mm	Pine Needles (dry)	Pine Needles (11 %)
25	NI	NI
50	NI	NI

0.5 m/s

Ember Size (mm	Pine Needles (dry)	Pine Needles (11 %)
25	NI	NI
50	SI To FI	SI to FI

1.0 m/s

The following conclusions were drawn from the pine needle bed experiments. Pine needle bed ignition was only observed for glowing firebrand impact under conditions of multiple firebrand deposition. The sizes of the firebrands, as well as the degree of the air flow, were important parameters in determining ignition.

It is useful to compare the present pine needle results with those obtained by Ellis (2000). Under all conditions considered in the present study, it was possible to produce flaming ignition of pine needle beds from flaming firebrand impact (minimum firebrand mass for ignition was 1g). This result agrees qualitatively with the findings of Ellis (2000). No ignitions were observed presently for pine needle beds as a consequence of single glowing firebrand impact over the range of moisture contents studied. Smoldering ignition with a subsequent transition to flaming ignition was observed when four 50 mm glowing firebrands (mass = 6.0 g) were deposited into the pine needle beds, with an air flow of 1 m/s (over the range of pine needle moisture content considered). The results obtained for glowing firebrand impact differ from those of Ellis (2000). The main reasons for the differences between the present study and that of Ellis (2000) may be due to: (1) differences in firebrand geometry, and (2) firebrand composition (eucalyptus firebrands versus ponderosa pine firebrands). Woycheese (2001) has shown that the particular species of wood influences the burning process. This, in turn, may influence the characteristics of the glowing firebrand generated.

CONCLUSIONS

This paper has described an apparatus that was constructed to investigate the ignition propensity of the materials due to the impingement of firebrands. The apparatus allowed for the ignition and deposition of single and multiple firebrands onto a target fuel bed. The ability to deposit multiple firebrands onto a target fuel bed is important, as most homes and other structures are bombarded by firebrand showers in urban-wild-land interface fires. The moisture content of the fuel beds used was varied and the test fuel beds considered were pine needle beds. The FE/DE was used here as a wind tunnel to investigate the influence of an air flow on the ignitability of fuel beds.

The results obtained for the pine needle beds suggest that a shower of glowing firebrands is required to ignite pine needle beds, under the range of firebrand sizes considered here. For single flaming firebrands, it was possible to ignite pine needle beds. Based upon these findings, the flux of firebrands, the size of the firebrands as well as the degree of the air flow were important parameters to determine the ignition propensity of a fuel bed. It is desired that these results, in conjunction with other literature studies, will be used to validate firebrand ignition models.

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