Urban-Wildland Fires: On the Ignition Of Surfaces By Embers[1]

Samuel L. Manzello[2], Thomas G. Cleary, John R. Shields, and Jiann C. Yang
Building and Fire Research Laboratory (BFRL)
National Institute of Standards and Technology (NIST)
Gaithersburg, MD 20899 USA

ABSTRACT

An experimental apparatus has been built to investigate the ignition of surfaces as a result of impact with burning embers. The apparatus allowed for the ignition and deposition of both single and multiple embers onto the target surface. The moisture content of the surfaces used was varied and the test surfaces considered were pine needle beds and shredded paper beds. Embers were simulated by machining wood (*pinus ponderosa*) into small disks of uniform geometry and the size of the disks was varied. Ember simulation was necessary since it is difficult to capture and characterize embers from an actual burning object. The ember 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 a surface. Results of this study are presented.

INTRODUCTION

Urban-wildland fires have plagued the United States for centuries. Recent urban-wildland fires include the 2002 Hayman Fire, the 2000 Los Alamos Fire, and the 1991 Oakland Hills Fire[1]. 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.

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

Unfortunately, a dearth of information is available in the open literature regarding the ignition propensity of surfaces in contact with burning embers. To the authors' knowledge, the only detailed study that exists was performed by Waterman and Takata[2]. The lack of specific knowledge on the ability of embers to ignite remote objects limits the utility of detailed computation fluid dynamic models (CFD) that could be used to predict fire spread by fire brands.

It is believed that pine needles in the gutters of homes are susceptible to ignition by ember showers. In addition, embers may be blown in the attics of homes and ignite materials stored there (*e.g.* paper, clothing). To the authors' knowledge, no study in the open literature has tested these suppositions under laboratory scale conditions.

Consequently, the goal of this study is to understand how lofted embers created by urban-wildland fires ignite the impacted surface. 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 embers. The apparatus allowed for the ignition and deposition of single and multiple embers onto a target surface. The ability to deposit multiple embers onto a target surface is important, as most homes and other structures are bombarded by ember showers in wild-land urban interface fires. The moisture content of the surfaces used was varied and the test surfaces considered were pine needle beds, and shredded paper beds. Shredded paper beds were used as a surrogate for typical cellulosic fuels that would be found in attic spaces. 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 surfaces.

EXPERIMENTAL DESCRIPTION

Figure 1 is a schematic of the experimental apparatus used for the ember impact studies. The ember ignition apparatus consists of four butane burners and an ember mounting probe. The butane flowrate is controlled by a metering

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[2] Corresponding author: +1-301-975-6891 (office) +1-301-975-4052 (fax) email: samuel.manzello@nist.gov

valve coupled to a solenoid valve. The ember, or in the case of multiple ember impact, embers, are held into position and the air pressure is activated, which moves the actuator and clamps the ember(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 embers 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 ember (s). The retraction of the burner upon ignition and the free-burn time of the embers are computer controlled which ensures repeatability. Each butane burner was designed to be switched on or off, depending upon the number of embers needed for the particular experiment.

As mentioned, the experimental apparatus was designed to simultaneously release and deposit multiple embers. It was important to space each ember carefully when performing multiple ember ignition studies. The reason for this is that it was desired to simulate the flux of multiple embers onto a surface. If the embers were aligned too closely, they would not burn in the space between each ember. As a result, under such conditions, it was not possible to produce glowing embers. Therefore, a series of brass spacers were used to hold the embers in place. Up to 4 embers were loaded into the ember ignition apparatus.

The ember ignition apparatus was installed in the duct of the FE/DE. The FE/DE is described elsewhere[3-4] 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 thru laser doppler velocimetry (LDV) measurements.

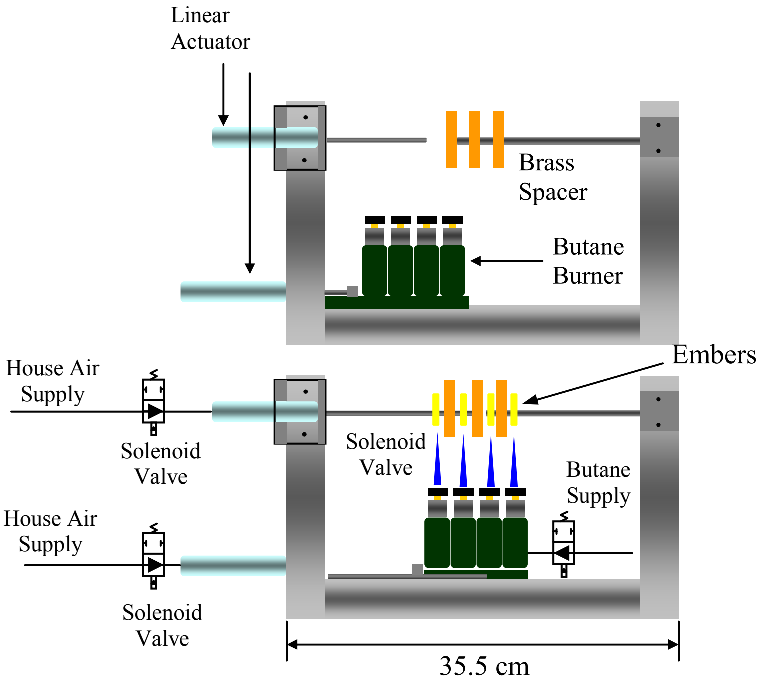

Fig. 1 Schematic of the ember ignition and release apparatus. The schematic demonstrates the loading process for a four embers.

Embers were simulated by machining wood into sections of uniform geometry. Ember simulation was necessary since it is difficult to capture embers from burning objects[2]. An important consideration in simulating embers is the size and shape[5-6]. Both the size and shape are important factors as it is these properties that determine the lofting characteristics and burn time of the embers.

For the present study, embers 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[6]. In addition, disks of this size range are capable of being lofted over long distances[6].

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-wildand 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.

Two different materials were used as test surfaces for the ignition studies: (1) pine needles, and (2) shredded paper. The impact of burning embers on pine needle beds was designed to simulate the showering of embers into gutters. Shredded paper beds were used to simulate ember impact upon materials within attic spaces. The pine needles and shredded paper were contained in aluminum foil pans of 23 cm long by 23 cm wide by 5.1 cm deep. The moisture content of these materials 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 and shredded paper beds

The ember ignition process and release onto the target surfaces 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 surface due to ember impact.

RESULTS AND DISCUSSION

In the ember transport process, the embers are formed, ignited, and land upon surfaces. In order to be a threat to the environment, the embers must land on surfaces and still be burning. Therefore, it is important to determine the burning history of the simulated embers as a function of disk size and air flow. Embers were ignited for a fixed duration and were allowed to free burn. The embers were then released onto a load cell and the burning history of the embers was obtained from the gravimetric measurements. Figure 2 displays results obtained for *pinus ponderosa* disks. Each data point is the average of five measurements and the error bars display the standard deviation.

Three conditions are shown in the figure: (1) no air flow (2) air flow of 0.5 m/s and (3) air flow of 1.0 m/s. Under air flow conditions, the embers were ignited under low flow conditions and the air flow was ramped up as soon as the ignition process was over. The ignition time for 25 mm and 50 mm embers was 30 s and 45 s, respectively. Under zero air flow conditions, the ember remained in a flaming state. When an air flow was introduced, the air flow blew off the envelope flame from the leading edge of the ember and gradually blew the flame off the back side of the ember. After the flame was blown off, a glowing ember resulted. The time for flame blowoff was observed to decrease with an increase in air flow velocity.

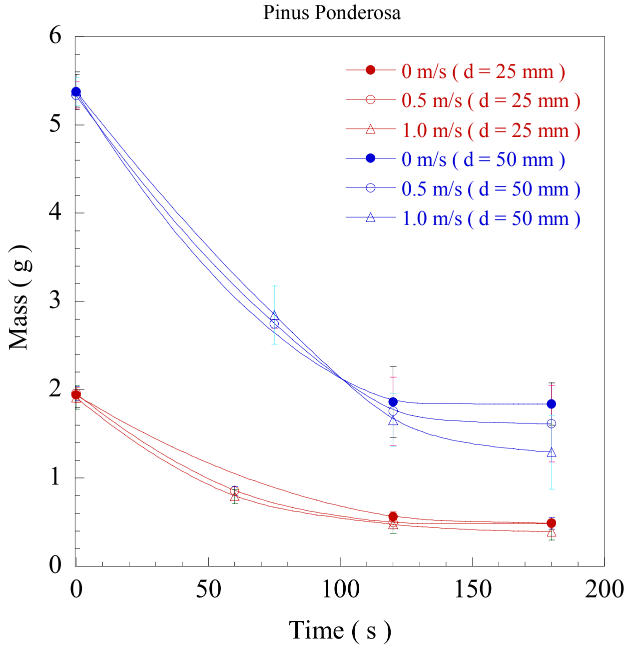

Fig.2 Variation of ember mass loss as a function of air flow velocity.

The embers were released onto the target surfaces in both a flaming state and a glowing state. It has been suggested that embers fall at or near their terminal settling velocity. As such, when embers contact ignitable surfaces, they are *most likely* in a state of glowing combustion, not open flaming[2,5]. However, from figure 2, it is possible for embers to remain in a flaming state under an air flow and therefore it is reasonable to assume that some embers may still be flaming upon impact. As a result, the ignition propensity of the pine needle beds and shredded paper beds was assessed based upon *both* glowing and flaming ember impact.

SINGLE EMBER IGNITION STUDIES

Experiments were performed for single ember impact (both flaming and glowing) to investigate whether it was possible to ignite substrates under such conditions. Figure 3 displays characteristic images of glowing embers which were released onto the substrates. The results obtained for single glowing ember 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 ember sizes tested and the experimental combination tested, it was not possible to ignite pine needle beds from single glowing ember impact. After the ember impacted the pine needle bed, one or two needles would smolder and the smolder front would not propagate further in the bed.

Table 2 displays results obtained for single glowing ember impact into shredded paper beds. The acronym SI denotes smoldering ignition. From the table, smoldering ignition was possible for single ember impact. Presently, smoldering ignition was defined when the smoldering front propagated outwards from deposited ember into the bed. When the shredded paper beds were dried, smoldering ignition was observed in all cases. As seen in table 2**,** as the moisture content of the shredded paper bed was increased, ignition was not possible for the 25 mm embers under the conditions of an air flow of 0.5 m/s. As the air flow was increased, it was possible to ignite shredded paper at 11 % moisture using the 25 mm embers. It was observed that single glowing embers posed an ignition danger only to shredded paper beds.

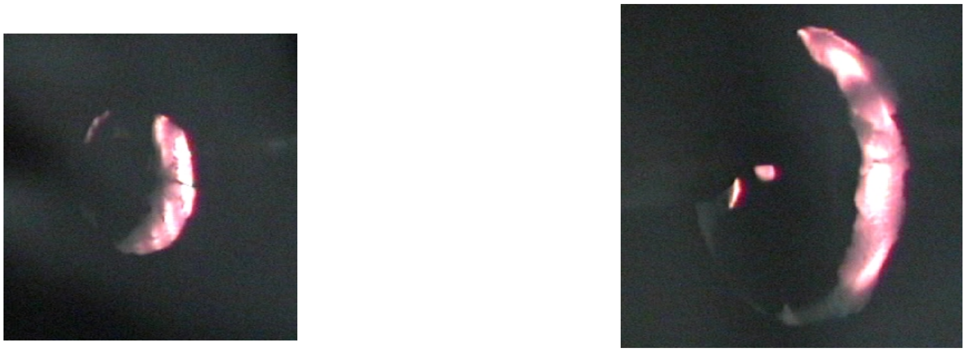

Fig. 3 (a) Glowing ember, d_0 = 25 mm (b) Glowing ember, d_0 = 50 mm.

Tables 3 and 4 display the results for single flaming ember impact onto pine needle beds and shredded paper beds. To produce flaming embers, the embers 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 ember impact when the embers were released in a flaming state onto pine needle beds and shredded paper beds. These results suggest that if the embers are in flaming mode, only a single ember is required to begin an ignition event for these materials. The ignition process due to a single flaming ember impacting a pine needle bed is shown in figure 4.

Table 1 Glowing ember ignition data for single ember impact on 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

Table 2 Glowing ember ignition data for single ember impact into shredded paper beds.

Ember Size (mm)	Shredded Paper (dry)	Shredded Paper (11 %)
25	SI	NI
50	SI	SI

0.5 m/s

Ember Size (mm)	Shredded Paper (dry)	Shredded Paper (11 %)
25	SI	SI
50	SI	SI

1.0 m/s

Fig. 4 Single flaming ember which produced flaming ignition in a pine needle bed held at 11% moisture, d_0 = 25 mm.

Table 3 Flaming ember ignition data for single ember impact in 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

Table 4 Flaming ember ignition data for single ember impact into shredded paper beds.

Ember Size (mm)	Shredded Paper (dry)	Shredded Paper (11 %)
25	FI	FI
50	FI	FI

0.5 m/s

Ember Size (mm)	Shredded Paper (dry)	Shredded Paper (11 %)
25	FI	FI
50	FI	FI

1.0 m/s

MULTIPLE EMBER IGNITION STUDIES

It was apparent from the single ember ignition studies that it was possible to ignite shredded paper beds from single glowing ember impact. This result suggests that it may not require a large flux of embers to ignite a home, provided that the embers are able to penetrate into attic spaces. The results obtained for the pine needle beds suggest that a shower of glowing embers is required to ignite structures when embers impinge upon materials found outside structures. Therefore, based upon these findings, the flux of embers is clearly an important parameter which must be considered.

Consequently, the experiments were repeated, but now multiple embers were deposited upon the pine needle beds. Since ignition was possible under conditions of single ember impact for shredded paper beds (both glowing and flaming,) multiple ember impact experiments were not performed using this material. In addition, single flaming embers were able to ignite pine needle beds and shredded paper, thus multiple flaming ember experiments were not conducted for these materials.

Table 5 displays results obtained for multiple glowing ember impact upon pine needle beds. From the table, the deposition of four 25 mm glowing embers did not produce an ignition event under the conditions tested. For the 50 mm glowing embers, smoldering ignition was observed to occur when four embers 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 embers did not produce an ignition. When four 50 mm embers 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 5 Glowing ember ignition date for multiple ember 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 ember impact under conditions of multiple ember deposition. The size of the embers as well as the degree of the air flow were important parameters in determining ignition.

CONCLUSIONS

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

It was apparent from the single ember ignition studies that it was possible to ignite shredded paper beds from single glowing ember impact. This result suggests that it may not require a large flux of embers to ignite a home, provided that the embers are able to penetrate into attic spaces. The results obtained for the pine needle beds suggest that a shower of glowing embers is required to ignite structures when glowing embers impinge upon materials found outside structures. For single flaming embers, it was possible to ignite pine needle beds and shredded paper beds. Based upon these findings, the flux of embers, the size of the embers as well as the degree of the air flow were important parameters to determine the ignition propensity of a surface.

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