Flammability of Christmas Trees and Other Vegetation

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Introduction

Vegetation can play a critical role in fires involving structures. Two specific examples are evergreen trees used as decoration indoors during the Christmas season and outdoor vegetation near structures in the wildland-urban interface. The fire safety of vegetation involves its tendency to ignite and the heat generated by the burning vegetation. This paper reports on two recent series of tests involving Christmas trees. In the first series, fire investigators in Minnesota conducted tests on different ignition sources. In the second series, the USDA Forest Service Forest Products Laboratory (FPL) determined the fire intensity of burning trees when ignited by a fairly large ignition source. This paper refers to a study on the flammability of ornamental plants for use near homes in the wildland-urban interface, in which a cone calorimeter was used to evaluate the relative flammability of vegetation (White and others 1996). The recent tests involving Christmas trees provided the opportunity to obtain some comparative data.

Literature Review

Fire Statistics

According to the National Fire Protection Association (NFPA 1997), nearly 600 fires per year in the United States are started by ignition of Christmas trees. For recent years, these statistics also indicate that about 510 of these fires occur in homes; resultant deaths (average of 33 deaths/year) also occur in homes. On average, such fires result in 112 injuries and $21 million in direct property damage per year. The NFPA data for 1965 indicated that about 1,450 fires involved Christmas trees (Holmes 1969). Fires associated with Christmas trees are not limited to natural trees. Incidents of fires involving artificial trees have been reported in the NFPA Journal.

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Fire Retardant Treatments

Treatments to improve the fire safety of Christmas trees have included additives to the water and fire-retardant coatings. In the ealy 1950s, research by FPL (1952) resulted in a recommendation to place the tree stem in plain water rather than chemical solutions. In the late 1960s, FPL conducted an in-house investigation of the effectiveness of additives in the water (Holmes 1969). The research confirmed the superiority of water alone over the use of such additives as corn syrup and a mineral supplement formulation. In tests with 1.8-m Scotch pine trees, the trees set in water alone absorbed an average of 10.2 kg of water during the 15-day test period, or 1.5 kg of water/kg of tree. This absorption was seven times greater than that obtained with a water solution contacting corn syrup and three times greater than that with the mineral supplement. Greater water pickup results in higher foliar moisture content, which provides the best ignition resistance. The use of some fire-retardant chemicals in the stem water supply was also investigated and found to be ineffective. Only a small quantity of a fire-retardant chemical can be absorbed in this manner. Similar conclusions in favor of plain water had been reached by Van Wagner (1963).

Fire-retardant coatings for Christmas trees are discussed in the NFPA *Fire Protection Handbook* (Shaw 1997). To be effective, the coatings need to be thick or syrupy enough to result in a fairly heavy coating on the tree. Simple water-dissolved solutions of inorganic salts are not sufficiently effective once the tree is dry. As noted by Tryon (1959), testing a tree immediately after treatment does not reveal whether the treatment is effective since a freshly cut tree would not tend to catch fire. Data of Dr. Chastagner of Washington State University showed that flame-retardant chemicals can cause accelerated drying, discoloration, and loss of needles (Damant and Nurbakhsh 1994). Formulas for fire-retardant coatings for Christmas trees were listed in FPL Technical Note 250 (FPL 1952), but FPL no longer recommends their use. The general consensus is that the best protection is obtained by getting a tree with high natural moisture content, cutting off a portion of the stem, and keeping the stem continuously supplied with plain water.

Christmas Tree as Source of Room Fires

In recent years, heat release rate (HRR) curves have been obtained for burning Christmas trees. Ahonen and others (1984) obtained HRR curves for three Christmas trees (Babrauskas 1995). One tree that had been cut and left outside was taken into a 15°C room for 2 days. After ignition with a small amount of isopropanol, the tree burned only sporadically, with a peak HRR of only 69 kW. The other trees were dried out with heat lamps. These trees burned vigorously, with peak HRRs of 500 and 650 kW. Damant and Nurbakhsh (1994) tested nine Christmas trees in a test burn room. Both weight loss and HRR were measured. In the six tests of dry trees, the peak HRR ranged from 786 to 1,667 kW. The weight of the trees ranged from 3.0 to 11.8 kg. Total burn times ranged from 1 to 4 min. In many of the tests, flames came out of the doorway of the room. In the single test of a freshly cut tree, the peak HRR was only 11 kW (no ignition was obtained).

Ignition Propensity of Christmas Trees

A study by the Department of Forestry-Canada (Van Wagner 1963) demonstrated the value of keeping the butt of the tree in water. For trees that stand in water, maintaining foliar moisture content over 100% , ignition with matches is not possible. Below about 50% foliar moisture content, Christmas trees ignite readily from matches, and at less than 20% , they burn with great violence. A tree that has dried below the moisture recovery limit (foliar moisture content of 75% to 85%) will continue to dry even though standing in water. As discussed by Holmes (1969), the needles draw water from the stem. A stem that has dried out is no longer able to effectively transport water to the foliage. Van Wagner (1963) also found that no matter how high the foliar moisture content, flames in a ring at the base of the tree from burning materials, such as gift wrap, ignite the crown. Fire tests involving 0.45 kg of shredded newspaper around the base of the tree as an ignition source showed the fire retardance of higher moisture-containing trees in terms of ignition time, maximum flame height, time to maximum flame height, temperature development, and irradiation heat (Holmes 1969). Damant and Nurbakhsh (1994) found that dried Christmas trees could be easily ignited with a single paper match to a lower branch. However, ignition of a freshly cut tree was not obtained with a match or match-ignited polyester fiber batting as the ignition source.

Test Projects

Minnesota Christmas Tree Tests

Fire investigators were suspicious of a claim that a shorted wire on a Christmas tree ignited the tree and caused extensive damage to a house. A preliminary test was done on discarded Christmas trees to see how easily they would ignite. Initial tests showed that it was very difficult to get a Christmas tree to sustain flame when ignition was caused by some ordinary means, such as a shorted wire, a match, or a cigarette. A second series of more controlled tests was conducted from April to May of 1997. That series is reported here. In these tests, four methods of ignition were applied to a series of trees to determine whether ignition could be sustained.

FPL Christmas Tree Tests

In December 1995, FPL was contacted by a local fire department, who were having difficulty in igniting a tree for a fire safety demonstration for the holiday season. Although FPL could not provide any assistance in time for the holidays, researchers studied this problem in conjunction with an ongoing study. At that time, researchers were investigating the use of the cone calorimeter to evaluate the relative flammability of vegetation used to landscape homes in the wildland-urban interface. The cone calorimeter measures the HRR of a small burning specimen exposed to a constant external heat flux. Since fill-scale test data for these plants were not yet available, four fill-scale tests of discarded Christmas trees were conducted in the room/comer test facility to compare with cone calorimeter data obtained on the tree foliage.

FPL Ornamental Plant Tests

Homeowners are often advised to remove highly flammable vegetation and other such materials that are adjacent to their homes because such vegetation can result in ignition of the structure. The objective of the FPL project on ornamental plants is to improve the reliability and scope of information on the relative flammability of native and ornamental plants that could be used for landscaping. Preliminary test results (White and others 1996) are presented here.

Methods

Minnesota Christmas Tree Tests

Materials

An effort was made to obtain trees in a manner consistent with normal practice. A Christmas tree grower, who is also on the University of Minnesota staff at the Agricultural campus, assisted by (1) providing a cutting schedule similar to one followed by members of the Christmas Tree Growers Association-certain types of trees are cut at certain times during the holiday season, and (2) providing a chart of average temperatures during the holiday growing and cutting season.

The average temperature chart was used to cut and store nine trees during the Spring when temperatures were comparable to Fall growing and cutting temperatures. The trees were cut according to the growers' practices. Pines were cut about 6 weeks before being set up in stands indoors; spruces and firs were cut about 2 weeks before being set up; and a selection of trees were cut "fresh" and set up immediately in stands full of water. Some trees were bundled. Bundling is supposedly a major factor in how fast a tree dries out. Two trees that had been cut the previous October (6 to 7 months before the burn room test), bundled, and placed in a pile were included in the tests. As a result, there were four conditions prior to the tests on May 3, 1997 (Table 1).

All the trees were re-cut at the bottom of the trunk, placed in a Christmas tree stand, and maintained in water for 2 weeks. Except for the trees cut in October 1996, all trees were placed in

Table 1. Conditioning of trees prior to MN fire tests

Condition	Date cut	Initial conditioning	Final conditioning (April 16 to May 3)
A	April 12, 1997	Immediately placed in water	Bottom trimmed off; tree inserted in water and kept in apartment.
B	April 7, 1997	Bundled	Bottom trimmed off; tree inserted in water and kept in apartment.
C	March 1, 1997	Not bundled; laid in pile	Bottom trimmed off; tree inserted in water and kept in apartment.
D	October 1996	Bundled; left in storage	Bottom trimmed off; tree inserted in water and kept in garage.

an apartment maintained at a constant temperature of 19°C. The October-cut trees were stored in a garage where the temperatures were cool and variable.

Test Procedure

The trees were tested in a burn tower in St. Paul. The bum room, which was the size of a large bedroom, was preheated until the wall temperature was 21°C. Each tree was set up in the corner of the room, as is customary in many houses, and ignited in one of the following ways:

1. A match was held to a branch for up to 8 s.
2. The flame from a lighter was held to a branch for up to 8 s. Near the conclusion of the test series, the flame was held to a branch for 20 to 30 s on two different trees.
3. A sustained electric arc was held on a branch for up to 8 s.
4. An overheated wire was held to a branch until the wire broke and the current was interrupted.

All the forms of ignition were chosen to simulate an “accidental” fire in an ordinary house, either from faulty lights or wires, or from candles, cigarettes, or lit matches in the vicinity of the tree. None of the trees was sprayed with a fire accelerant.

After the bum room tests, samples were sent to FPL for testing in the cone calorimeter. One test was conducted on materials from each tree, After the cone calorimeter tests were completed, remaining materials were tested for moisture content.

FPL Christmas Tree Tests

Trees used for FPL tests are described in Table 2. The HRR of the burning vegetation sample was measured in both the cone calorimeter tests and full-scale tests. The fill-scale tests of the four Christmas trees were conducted in the room/corner test facility. In the initial test, the ignition source was 0.45 kg of shredded paper and 100 ml of methanol. In subsequent tests (two to four tests), the amount of paper was reduced in half. Measurement of oxygen, carbon monoxide, and carbon dioxide in the exhaust allowed the calculation of the heat release as is done in the cone calorimeter. After the full-scale tests, samples of the foliage (three replicates) were tested in the cone calorimeter.

Table 2. Description of trees in FPL tests

Tree no.	Species	Foliage height (m)	Tree diameter (m)	Initial weight (kg)
1[a]	White pine	1.6	1.1	5.0
2	Red pine	1.8	1.2	7.2
3	Fraser fir	1.9	1.4	13.1
4	Balsam fir	1.8	1.3	4.5

[a] This tree was kept outside. Histories of other trees are not known.

FPL Ornamental Plant Tests

As part of this project, samples of 10 different plants obtained at one time were tested as green and ovendry samples (White and others 1996). Three replicates of each sample were tested. Testing of samples obtained at four different times of the year are part of the overall project.

Cone Calorimeter

The cone calorimeter is an oxygen consumption calorimeter described in ASTM E 1354 (ASTM 1994). The sample size is 100 mm square. The operator places Enough samples in the holder to make only a single layer of foliage. The main result of the test is a curve of heat release rate versus time. To express this curve as a single numerical result, the peak and the average HRRs over a fixed period from ignition are calculated from the curve. These results are normally expressed as kilowatts per square meter of exposed surface area. Other results include total heat release, effective heat of combustion, and time for sustained ignition. The effective heat of combustion is the average heat release per mass loss.

All the cone calorimeter results presented in this paper are for external heat flux exposure of 25 kW/m^2. Foliage was placed in the sample holder with the frame and grid over the top.

Results

Minnesota Christmas Tree Tests

None of the trees ignited with the ignition sources that represent “accidental” ignition (Table 3). Often a few needles would begin to burn, but once the flame source was taken away, the tree self-extinguished within a second or two. In the case of Tree 10, ignition occurred with the 2-s and 8-s exposures to a lighter but self-extinguished. After these ignition sources failed, a blow torch was applied to a tree for about 2-1/2 min. When the torch was removed, the tree self-extinguished within 5 s. Finally, four sheets of newspaper were crumpled and stuffed inside a tree, and the paper was lit with a blowtorch. The inside of the tree, where the needles were driest, burned 94 s and self-extinguished. A white pine cut April 7 was ignited with a propane torch held to it for 150 s. The tree self-extinguished within 5 s after the torch was removed.

The cone calorimeter results are given in Table 4. In the case of Tree 10, the heat release was high (effective heat of combustion (HOC) was 10 MJ/kg) and the ignition time was short (87 s). This is consistent with some ignition with the lighter in the MN tests (Table 3).

Table 3. Results of MN tests with different ignition sources[a]

Tree no.	Species	History	Matches			Lighter			Electric arc		Overheated wire	Blowtorch + paper
			8 s	20 s	30 s	2 s	4 s	8 s	4 s	8 s		
1	Blue spruce	A	NI	▨	▨	▨	▨	NI	▨	NI	▨	▨
6	Blue spruce	B	NI	▨	▨	NI	NI	NI	NI	NI	NI	▨
2	Norway pine	A	NI	▨	▨	NI	NI	NI	NI	NI	NI	▨
8	Norway pine	C	NI	▨	▨	NI	NI	NI	▨	NI	NI	▨
3	Scotch pine	A	NI	▨	▨	▨	▨	NI	▨	NI	▨	▨
9	Scotch pine	C	NI	▨	NI	NI	NI	NI	▨	NI	▨	▨
11	Scotch pine	D	NI	NI	▨	NI	NI	NI	▨	▨	▨	▨
4	Balsam fir	A	NI	▨	▨	▨	▨	NI	▨	NI	▨	▨
10	Balsam fir	D	NI	▨	▨	SE	NI	SE	▨	NI	▨	▨
5	White spruce	A	NI	▨	▨	▨	▨	NI	▨	NI	▨	Burned 94 s SE
7	White spruce	B	NI	▨	▨	▨	▨	NI	▨	NI	▨	▨

[a] NI = No sustained ignition once flame was removed; SE = Ignition occurred but self-extinguished. Shading indicates that no test was conducted.

Table 4. Calorimeter results for MN foliage samples

Tree no.	Species	History	Initial mass (g)	Moisture content (%)	Peak HRR (kW/m^2)	Effective HOC (MJ/kg)	Ignition time (s)
1	Blue spruce	A	16.4	55.2	90.9	6.2	232
6	Blue spruce	B	14.2	37.2	97.5	7.8	141
2	Norway pine	A	20.2	81.1	74.9	6.7	242
8	Norway pine	C	22.7	115.0	47.9	6.3	309
3	Scotch pine	A	13.1	50.4	77.2	6.7	140
9	Scotch pine	C	12.7	84.6	135.2	5.8	155
11	Scotch pine	D	14.3	137.3	84.3	5.9	235
4	Balsam fir	A	13.1	75.8	146.4	10.5	137
10	Balsam fir	D	6.7	80.9	141.2	10.1	87
5	White spruce	A	10.3	55.2	134.0	8.8	139
7	White spruce	B	9.9	97.2	110.9	8.1	130

FPL Christmas Tree Tests

For the tree kept over the test period (Tree 1), the peak HRR was 469 kW (Table 5). Trees 3 and 4 were drier and had peak HRRs of 1,250 and 777 kW, respectively. The larger tree had the 1,250-kW peak HRR. In these two tests, flames came out the door of the room. A test was also run with shredded newspaper as the sole ignition source. The paper itself had a peak HRR of 100 kW. Unfortunately, the data for Tree 2 were lost.

Tree 1 also had the lowest peak HRR (67 kW/m^2) in the cone calorimeter tests (Table 6). The data in Table 6 are averages of three replicates. The peak HRR for Tree 4 (216 MJ/m^2) was greater than that for Tree 3 (154 kW/ m^2). The ranking of these two trees was the reverse in the fill-scale tests. This was likely caused by the mass of Tree 3, which was nearly three times that of Tree 4.

Table 5. Results of January 1996 full-scale tests at FPL

Tree no.	Species	Mass loss (kg)	Peak HRR (kW)	Total HRR (MJ)
1	White pine	2.3	469	28
2	Red pine	3.6	—	—
3	Fraser fir	10.4	1,250	111
4	Balsam fir	3.6	777	34

Table 6. Cone calorimeter results for January 1996 FPL tests

Tree no.	Species	Initial mass (g)	Moisture content (%)	Peak HRR (kW/m^2)	Effective HOC (MJ/kg)	Ignition time (s)
1	White pine	8.7	114	67	7.1	140
2	Red pine	9.9	120	108	8.8	106
3	Fraser pine	9.9	28	154	14.5	61
4	Balsam fir	4.4	6	216	20.7	23

FPL Ornamental Plant Tests

The results of tests on ornamental vegetation are preliminary; the study has not yet been completed. The inclusion of these data here is for the purpose of comparing green and ovendry samples (Table 7).

Discussion

In the MN tests, the tree itself was the initial fuel. The intent was to determine the ease by which a tree could be ignited. None of the trees was decorated with ornaments; only the trees themselves were evaluated. The trees were cut and kept in an apartment to simulate a typical exposure resulting from being cut several weeks prior to being placed in a house or apartment. One of the two trees cut in October 1996 (Tree 10) was the only tree that resulted in even partial ignition with matches, lighter, electric arc, or overheated wire.

Trees were kept indoors for 16 days prior to the MN fire tests. The trees were either cut immediately before the 16-day period or on a schedule consistent with the cutting schedule of the industry. Even after the cone calorimeter tests, the measured moisture contents were 37% to 137%. Van Wagner (1963) found that Christmas trees with foliar moisture content below 50% are readily ignited with matches. Our failure to obtain ignition with accidental ignition sources supports the industry cutting schedule. If the proper procedures of cutting the stem and keeping it in plain water are followed by the consumer, our MN data support the position that the moisture content of the tree will likely be sufficient to make accidental ignition of the tree itself from matches, lighter, electric arc, or overheated wire very unlikely. However, if kept in hot or dry environments, trees will dry out quickly. Based on the literature, dry trees are capable of being ignited. A tree that is already dried out at the start of use should not be used indoors. The tree should be removed from a structure once the branches appear to be dry.

In the MN tests, we did not start a fire elsewhere in the room or allow such a fire to impinge on the trees. A hostile fire in the same room as the tree would eventually build up enough energy to ignite the tree. The amount of energy from a hostile fire would be many times greater than the energy from an “accidental” source right at the tree.

Table 7. Cone calorimeter results for green and ovendry samples from ornamental plants[a]

Species	Peak heat release rate (kW/m²)	
	Green	Ovendry
Olive	127	258
Chamise	102	246
Wild lilac	55	138
Toyon	55	111
Crimson-spot rockrose	52	151
Sageleaf rockrose	47	99
Prostrate myoporum	34	161
Saltbush	26	73
Rhagodia spinescens	34	87
Aloe	4	92

[a] Source: White and others 1996.

In the FPL tests, the initial fuel was paper piled under the tree. With such an ignition source, it is likely that any tree will ignite. Depending on their condition, these trees burned very vigorously. Conditions became such that a room with other combustible furnishings would be fully involved in the fire.

In comparing the cone calorimeter results of peak HRR and ignition times for MN and FPL trees, the MN trees were most like FPL Tree 1. Moisture content was also similar. Tree 1 had the lowest peak HRR of the FPL trees. FPL Trees 3 and 4, which burned most intensely in the FPL tests, had peak HRRs and ignition times that were higher than those of any of the MN trees, which suggests that FPL Tree 4 was much drier than the MN trees (Tables 4 and 6).

While there were few comparative data, the data do support the use of the cone calorimeter to evaluate the flammability of vegetation. The cone data for MN Tree 10 was consistent with its performance in the MN tree tests. Given the difference in mass, the cone data for the FPL trees were consistent with the fill-scale test results. Cone calorimeter testing is normally done on an exposed surface area basis. This presents a problem when materials such as foliage are tested. Additional work needs to be done on the test protocol.

Moisture content is the dominant factor in the fire behavior of vegetation, as can be seen in Table 7, which lists results for green and ovendry samples of different vegetation.

Because the number of tests and replicates were limited in this study, the data are such that no conclusions regarding differences between tree species should be made.

Conclusions

As evidenced by the Minnesota tests, a Christmas tree has so much natural moisture that it is very difficult for it to sustain a flame; in our study, even the tree cut more than 8 weeks prior to testing did not sustain a flame. Accidental causes are unlikely to destroy a tree completely. Igniting the branches was nearly impossible with normal "accidental" ignition sources. If a fire accelerant were used, if fires were started elsewhere in the room or in paper beneath the tree, or if drier trees were used, the results would be different. As shown in the FPL tests, if a Christmas tree is fully involved in a fire, it represents a significant and rapid heat source that will likely result in rapid flashover in the room of origin. In tests on a very dry tree, the burning tree itself satisfied some of the failure criteria used in room/corner tests, with a 1,000-kW heat release rate and flames spreading from the room out the door. The data support the use of the cone calorimeter to measure the relative flammability of vegetation,

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