Flammability of Cut Christmas Trees

by
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Class Learning Objectives:
  (1) learn how to judge the fire hazard for Douglas-fir Christmas trees;
  (2) learn how to take tree samples and test them;
  (3) case study presentation.

Abstract
Over 70 million Christmas trees are used in the United States each year. Approximately half of these are various species of natural Christmas trees. The interval of time between harvest and when trees are displayed indoors can be several weeks for trees shipped across country to less than one day for trees sold in local U-Cut markets. In addition, once trees are taken indoors, they are often displayed for several weeks during the holiday season.

Christmas tree keepability or postharvest quality and safety involves moisture and needle retention. The quality and safety of natural Christmas trees can decrease rapidly if they are handled improperly. Every year there are many popular articles written concerning the handling and care of Christmas trees. Unfortunately, they often contain erroneous information.

Although Christmas trees with high moisture levels do not burn when exposed to a small flame ignition source, problems can arise when trees are improperly cared for and dry out. Based on data from the National Fire Protection Association, Christmas trees (natural and artificial) are involved in about 500 fires per year. An average of 18 deaths, 108 injuries, and nearly $21 million in property loss results each year from Christmas tree-related fires.

Moisture level is the single most important factor in assessing the fire risk associated with the use of natural Christmas trees. Trees with low moisture levels can have heat release rate values of over 3 megawatts, which is one of the highest heat release rate values for any consumer goods or items in a typical residence.

Presentations during this workshop will provide an overview of factors affecting the moisture level of cut Christmas trees, discuss the relationship between moisture level and the flammability of shoots of various conifers used as Christmas trees, and present details on the results from two studies concerning a recent Christmas tree-related fire. These studies looked at the influence the quality of care and use of a fire retardant had on the moisture level and quality of Douglas-fir Christmas trees during a 10-day display period, and the influence moisture level and fire retardant application had on the fire risks associated with Douglas-fir Christmas trees. The full-scale fire test portion of theses studies involved over 102 trees.

I.

Christmas Tree Case Study

Presented by Eileen Stauss

A 4-year-old boy was seriously burned in a fire originating with a Christmas tree in his home a few years ago. Plaintiffs claimed that the Christmas lights ignited the fire, but also claimed that the Christmas tree retailer was liable for the child's third degree burns. The fire department took few photos; the tree was discarded, as were the Christmas lights.

The fire investigators for the Christmas tree retailer were able to examine the fire scene only through photos. The parents testified about their watering of the tree over a 10-day period, as well as the presence of various Christmas packages near the tree, including a small foam-stuffed dolphin placed onto the tree by the child. Interviews of witnesses and various photos of the floor were used to place various Christmas packages in relation to the tree.

To test the likelihood of the tree being a fire hazard, two studies were conducted. The first involved 48 Douglas-fir trees that were given different levels of care during a 10-day display period. In addition, half of the trees were sprayed with a commercial fire retardant to determine the effects this treatment had on the trees. The second study involved determining the flammability and heat release rates from Douglas-fir trees at the Western Fire Center in Kelso, Washington. These full-scale burn tests involved about 102 trees, including the trees from the 10-day display study. All of these trees were obtained from the same grower who supplied the tree to the retailer that was involved in the fire. Data of each burn test were evaluated.

II.

Factors Affecting the Moisture Levels of Cut Christmas Trees

Presented by Gary Chastagner, Ph.D.

Much of the information that follows is based on a recent review of research relating to the postharvest handling and care of cut Christmas trees by Hinesley and Chastagner. This and other references relating to various aspects of the handling, care and fire hazards associated with the use of cut Christmas trees are listed as references at the end of this section. Topics covered in this overview include methods used to measure the moisture status of cut trees, changes in the moisture status of trees from harvest through the display period, the effect of drying on the ability of trees to rehydrate when displayed in water, variation in moisture retention by different types of Christmas trees, water use during display, the effectiveness of water additives, antitranspirants and fire retardants and the relationship between moisture level and the flammability of shoots of various conifers used as Christmas trees.

Methods used to measure moisture levels. The two most common methods for determining the moisture level of trees are 1) twig moisture content (MC), and 2) water potential (ψ, pronounced "sigh"). MC is determined by sampling branches, weighing them, then oven-drying them at slightly above 100 C, and weighing them again.Percent MC is defined as:

$$MC = \frac{Mass_{wet} - Mass_{dry}}{Mass_{dry}} \times 100$$

Note that since the definition uses the dry mass in the denominator, moisture content can easily exceed 100%.

The second method utilizes a pressurized chamber to determine the water potential of the tree. A shoot with needles is sealed in a heavy-walled metal chamber so that the cut end is exposed outside the chamber. The chamber is pressurized until the pressure in the chamber is at equilibrium with the water potential of the shoots, at which time water appears on the exposed end of the shoot. As plants dry, the water in them is under increasing negative tension. Thus, the drier the twig, the greater the pressure required to reach an equilibrium and force water out of the cut end of the twig. Since we are actually measuring the negative tension or pressure thatthe water is under in plants, water potential units are express as negative bars. Freshly harvested trees normally have a ψ = -2 to –8 bars (10 bar = 1 mega pascal) and a MC of 120 to 160%. Although there is a high correlation between ψ and MC for a given species (Figure 1), a ψ of –30 bars does not correspond to the same MC value in a different species.
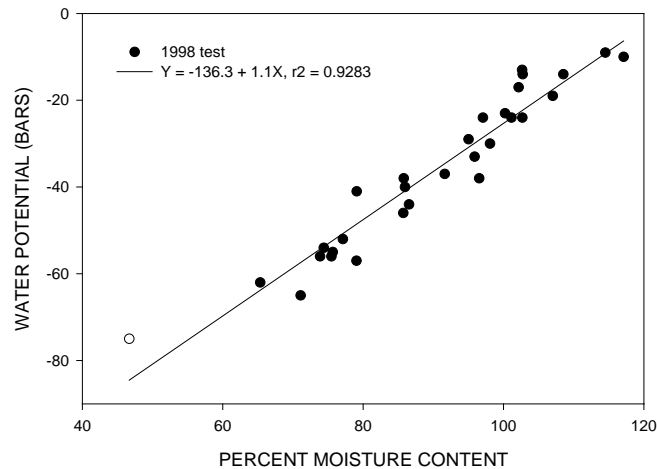
Figure 1. Correlation between water potential and moisture content for Fraser fir Christmas trees (Chastagner, unpublished data)

Changes in moisture levels after harvest. A natural Christmas tree contains a finite amount of water when cut. After harvest, the rate of drying is affected by species as well as environmental conditions (temperature, wind, etc.) and cold hardiness (dormancy). Moisture is lost from trees via small openings (stomata) that are present on the needles.

Under conditions that favor drying, trees dry quickly until they reach a point where the stomates close, which slows the rate of moisture loss. This point varies considerably by species. If drying continues, trees will reach a "damage threshold". Allowing trees to dry below this threshold results in irreversible damage (needle loss and discoloration and/or failure to rehydrate when placed in water) to the tree. The moisture level associated with this damage threshold also varies by species. For example, the damage threshold for eastern white pine, Douglas-fir and Fraser fir are around –30, -35 and –40 bars respectively. The time required to reach a particular damage threshold also varies by species. For example, eastern red cedar and Atlantic white cedar can dry very fast, whereas Fraser fir and noble fir dry much slower. The latter species are regarded as long-lasting Christmas trees, whereas the former two species have a short shelf life.

Moisture level also affects the ability of the tree to rehydrate when recut and displayed in water. Fresh cut trees typically have a MC in excess of 100%. When the base of a cut tree is trimmed and placed in water, the tree will typically rehydrate and reach a moisture level 5% to 10% above its MC at the time it was harvested, as long as the tree has not been allowed to dry below its damage threshold. Trees that have dried below their damage threshold may not be able to rehydrate when placed in water or if rehydration occurs, there may be adverse changes in quality (needle loss and discoloration).

The moisture level of trees during display varies among species and the type of care they are given during the display period. Species that last for a long time (e.g., noble fir and Fraser fir) tend to maintain a high MC and ψ for at least 4 weeks. Species that have a short shelf life (e.g., eastern red cedar or Atlantic white cedar) maintain a high water level for perhaps a week, and then begin to slowly dry even while displayed in water. This process is reflected by a decrease in ψ (more negative), a decrease in twig MC, and a reduction in daily water consumption.

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Moisture levels during storage, shipment and on retail lots. Harvest date is often used as an indicator of the freshness of a tree. The fact is that trees that have not dried below their damage thresholds behave the same as freshly cut trees when displayed in water, irrespective of their harvest date. Large growers typically begin harvesting trees in early to mid-November to insure that trees are available on retail lots that open in late November. Harvested trees are typically baled and stored outdoors for a few days to over a week prior to shipment to retailers. Studies have shown that limited moisture loss occurs from trees that are stored under cool, moist conditions. Shipping studies also indicate that limited moisture loss occurs from trees during shipment.

Most of the moisture loss that occurs between harvest and selection of the tree by the consumer occurs on the retail lot. The extent of drying is dependent on environmental conditions and how the trees are handled. Even in warm weather markets such as the southwest and Florida where the potential for drying is very high, retailers can prevent trees from drying below their damage threshold by protecting them from direct exposure to wind and sun, displaying trees in water and spraying trees with water at night.

Water use. Displaying trees in water is the most effective way of maintaining high moisture levels and minimizing fire hazards associated with the use of cut Christmas trees. There is often misinformation given about the care of trees in the popular press. Water uptake occurs via the woody part of the stem. The outer most rings of wood are the most efficient in taking water up. Removing ½ to 1 inch of the stem prior to placement in a stand is sufficient to maximize the uptake of water by the tree. The stem should not be cut at an angle and drilling holes in the center or sides of the stem is not beneficial.

After recutting, the tree should be set up in a stand and the stand filled with water. The temperature of the water is not important. Stem diameter is a much better indicator of the amount of water that will be used by a tree than tree height. Cut Christmas trees generally consume about 1 quart of water per day per inch of stem diameter. Thus, a tree with a 4-inch-diameter trunk would use about 4 quarts of water per day. The biggest mistake made by the consumer is using a stand with too little capacity, resulting in the stand "drying out" between refilling resulting in a tree that can no longer take up any water when it is added to the stand.

Compared to other species, true firs such as noble and Fraser fir tend to use large quantities of water over extended display periods. In contrast, the volume of water used by Douglas-fir decreases noticeably after about a week. From a practical standpoint, if a tree uses a relatively constant amount of water, it indicates that the tree is maintaining its initial moisture level. However, if there is a marked reduction in water consumption, the tree is beginning to dry.

Additives and preservatives. There are many commercially available chemical additives and home concoctions that are commonly recommended to be mixed with water in hopes of prolonging the life of cut Christmas trees. Research with these additives and preservatives have shown that they are of little benefit. Some additives can induce heavy needle loss and sometimes produce other adverse effects. The best tree preservative is plain water.

Antitranspirants. Application of antitranspirants to trees results in the formation a thin film on the surface of the needles. Although the use of these materials is often recommended to reduce the rate of moisture loss from various types of plants, they are generally not effective on Christmas trees. Under moderate to strong drying conditions, they do little to retard drying. In

some cases they also leave a sticky residue on the tree, which reduces its acceptability to the consumer.

Species comparisons. Over 30 species of conifers are used as Christmas trees in the United States and some species have better postharvest moisture and needle retention than others. The postharvest attributes of trees are based on their behavior during: 1) the time between cutting and displaying the tree indoors, and 2) the display period. Some species such as noble fir and Fraser fir do well in both phases. Others such as grand fir do poorly when displayed dry, but perform well in water. Some species have a short shelf life whether displayed wet or dry, e. g., eastern red cedar, and are not suited for wholesale marketing or long-term display in the home. Many true firs have excellent quality when displayed in water, but tend to shed needles when displayed dry.

The differences in the way true firs respond to how they are displayed can be illustrated with noble and Nordmann fir Christmas trees (Figure 2). When displayed in water, both species are able to maintain high moisture levels for extended periods of time. Trees displayed in water also shed very few needles. When displayed dry, it takes both species about 3 weeks to reach a water potential of –60 bars. The difference in the species can be seen in the extent of needle loss that occurs when the trees are displayed dry. Nordmann fir trees that are displayed dry begin to shed large numbers of needles as they dry while noble fir trees do not. The limited loss of needles and the relatively slow rate of drying are what make noble fir an excellent Christmas tree. The limited loss of needles from noble fir also points out a problem in using needle loss as an indicator of when a tree is dry.
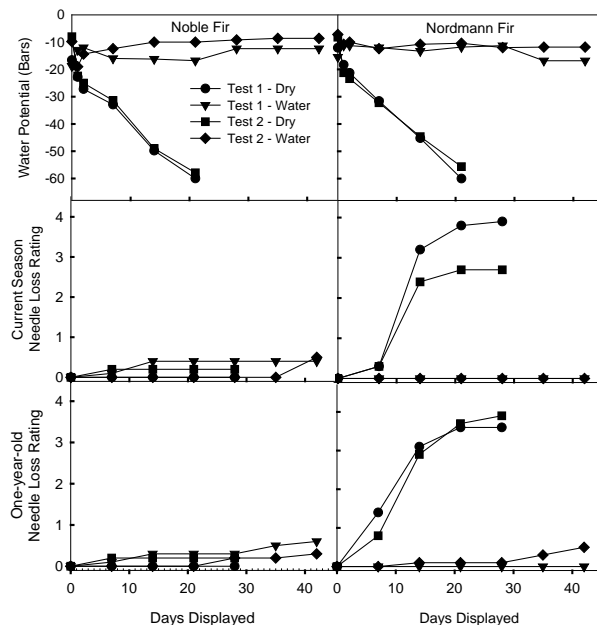

Figure 2. Effect of display condition (in water vs. dry) on the moisture status and needle retention by noble and Nordmann fir Christmas trees that were displayed indoors at 20C. Needle loss was rated on a 0 to 10 scale, where 0 = none and 10 = >90% loss. Each data point represents the average of five trees. (Chastagner, unpublished data)

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Fire retardants. Fire retardants are often suggested and in some cases required to be applied to Christmas trees in an effort to reduce potential fire hazards associated with dry trees. Very little work has been done on the effects of fire retardants on the postharvest quality of cut Christmas trees. Five fire retardants have been tested on Douglas-fir, noble fir and Monterey pine Christmas trees. All of the retardants included in this test adversely affected the quality of the trees. Some of the products caused extensive needle discoloration, increased needle loss and affected moisture retention. The apparent benefit of some products in maintaining moisture levels during display needs to be viewed in conjunction with the effect of these products on needle loss and damage. High levels of needle damage and the loss of large numbers of needles reduces the rate of moisture loss from displayed trees. Thus, one would expect to see higher water potentials in samples from trees that had been treated with products that caused extensive needle damage or needle loss because of the reduced needle surface area where moisture is lost from the tree.

In addition to adversely affecting the appearance of trees, many of the products did not significantly reduce the flammability of branch samples taken from treated trees. Based on these studies, fire retardants are not generally recommended for use on trees unless it is required by law. As recommended in a report by the California State Fire Marshals office, the best way to minimize potential fire hazards associated with cut Christmas trees is to have an effective educational program that teaches the importance of proper tree care and displaying trees in water-holding stands.

Relationship between moisture level and flammability of shoots of various types of Christmas trees. Christmas trees with high moisture levels are very difficult to ignite with a point source of flame. Problems can arise, however, when trees become too dry. Currently, field assessments of fire risks associated with cut Christmas trees are typically done by exposing a branch sample from a tree to a small flame. Very little information is available concerning the MC that different types of Christmas trees have to be at to fail this type of test.

Recent experiments involving over 20 conifer species have been conducted at Washington State University to determine the MC where branches initially begin to fail an ignition test, and the MC for consistent failure (Figure 3).   During these studies, 15.3 cm-long branch samples were exposed to a flame from a small alcohol lamp for 5 seconds. If the sample failed to burn or self-extinguished without any additional spread when the sample was removed from the flame, it passed the test. If there was any spread of the flame after the sample was removed from the flame, it failed the test. Results from these tests indicates that there is considerable variation in the MC where different species failed this test. In addition, there is often a large transition zone of MC from the point of initially failing the flammability test to the point where samples consistently fail. There is also a difference in the MC where samples fail the test and the MC when samples are totally consumed by the fire.   For example, Douglas-fir begins to fail the branch flammability test at about 68% MC, but is totally consumed only when dried to about 30% MC (Figure 4).
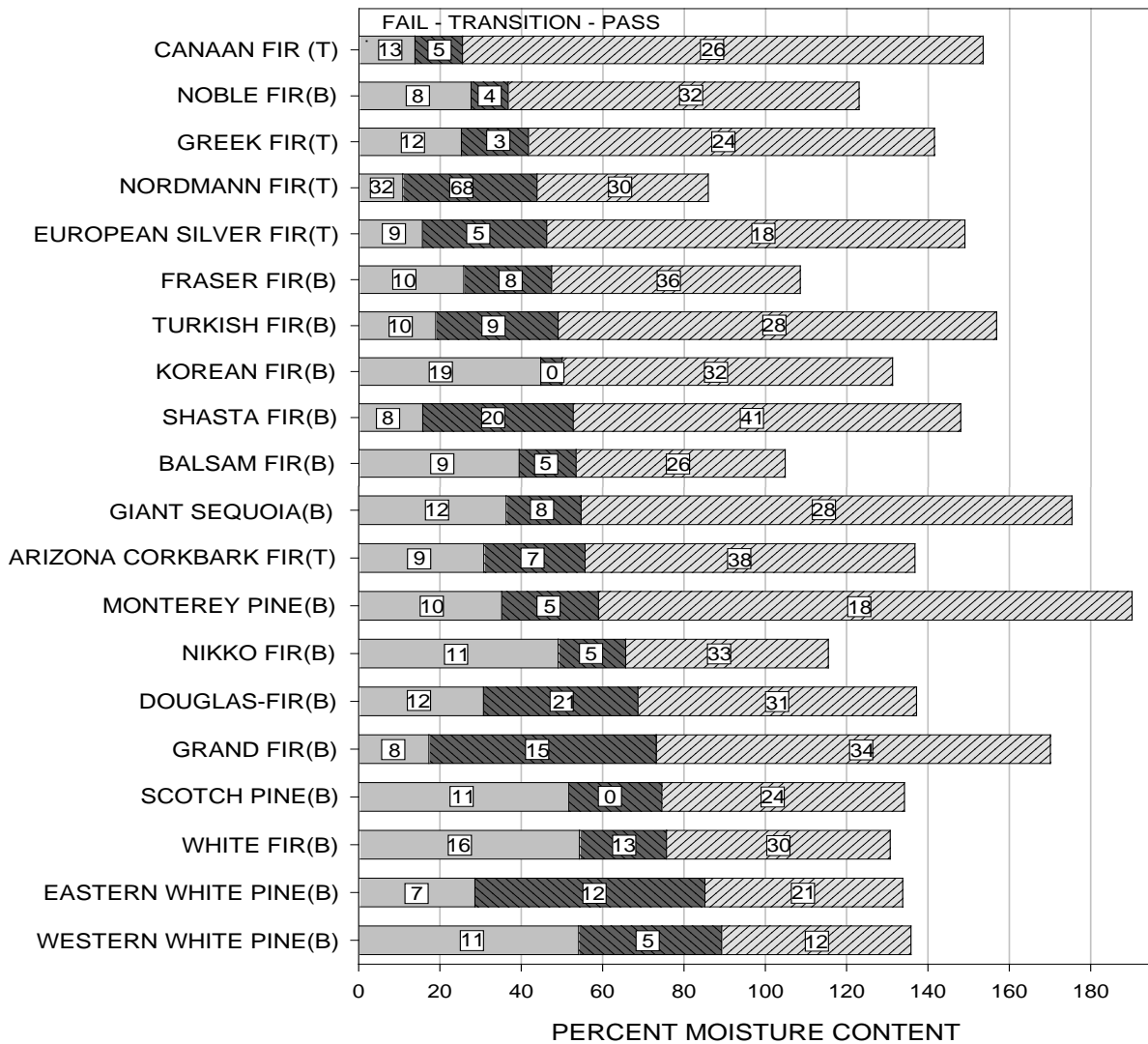
Figure 3. Summary of the relationship between moisture content and the ability of branch samples of 20 different types of Christmas trees to pass a modified California State Fire Marshal's field flammability test. Bars show the moisture range where samples pass or fail the test as well as the size of the transition zone where some samples pass and some fail. Numbers in small boxes are the number of samples tested. (T) = samples obtained from branches on whole trees. (B) = samples obtained from detached branches. (Chastagner, unpublished data)
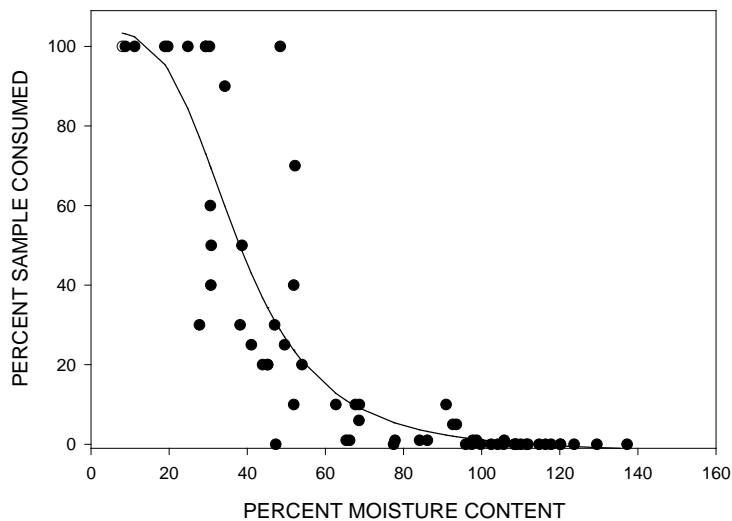
Figure 4. Relationship between moisture content and the percentage of the Douglas-firbranch sample consumed following exposure to a small flame. (Chastagner, unpublished data)

Based on this and other postharvest display data, one can estimate how long it would take for trees to dry to moisture levels where they would fail this test. For example, with noble fir twig MC must reach about 37% before it begins to fail the flammability test. This corresponds to a ψ below –60 bars. When displayed under typical room conditions, it will take about 2 weeks for noble fir trees that are displayed without water to dry to the point where they will begin to fail this type of a branch flammability test. When trees are displayed in water and given proper care, noble fir can easily be displayed for 4 to 6 weeks without drying to the point where it would fail this flammability test.

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III.

Studies Related to Case

Two studies were conducted relating to the "case study" discussed above (Section I). These studies looked at the influence the quality of care and use of a fire retardant had on the moisture level and quality of Douglas-fir Christmas trees during a 10-day display period and the influence moisture level and fire retardant application had on the fire risks associated with Douglas-fir Christmas trees. The full-scale fire test portion of these studies involved over 100 trees.

General procedures – Douglas-fir trees were obtained from the same Christmas tree grower in western Oregon that supplied trees to the retail lot operator who was a defendant in the above-referenced case. The trees were harvested, baled and transported to the Seattle area on January 9, 1996. Upon arrival, individual trees were tagged and then stored outside until they were brought into a temperature-controlled display room that was maintained at 21C and 45 to 55% relative humidity. Trees were displayed for two purposes. The first involved a replicated experiment to examine the effects of different levels of care and the use of Evergreen Christmas Tree fire retardant (Peak Season, Inc., Camarillo, CA) on the postharvest quality and fire hazard of the trees after a 10-day display period. Secondly, additional fire retardant-treated and untreated trees were also displayed for various periods of time to obtain additional trees that varied in moisture level for use in whole tree flammability tests to determine the correlation between moisture content of trees and their fire hazard.

IV.

Effect of Fire Retardant Application and Display Care on the Postharvest Quality of Douglas-fir Christmas Trees

Presented by Gary Chastagner, Ph.D.

Introduction

The level of care that is given to Christmas trees during the time they are displayed indoors has a tremendous effect on tree quality[1,2,3,4,5,6]. When displayed dry with minimal care, trees can dry very rapidly. However, if trees are displayed in water-holding stands and the water level in the stand is not allowed to drop below the base of the tree, some types of trees can maintain high moisture levels for 6 weeks or longer. Although there is considerable information about the effects of displaying trees in water or displaying them dry, very little information is available concerning what happens to trees that receive intermediate levels of care. In the above referenced case, the Douglas-fir Christmas tree was displayed for a period of 10 days prior to the fire. It was unclear exactly what quality of care was given to the tree during this time, so a test was done to determine the effect of different levels of display care on the moisture level and flammability of Douglas-fir trees. In addition, half of the trees were sprayed with a fire retardant to determine the effects this treatment had on the trees.

Test procedures

On January 11, 13, 15, and 18th, 12 trees were brought into the display room and unbaled. These trees were trimmed to a height of 6.5 feet, weighed and placed on a "center peg rebar" type tree stand to allow any moisture on their needles to dry prior to applications of the fire retardant. Half of the trees were then sprayed with a fire retardant and half were sprayed with water. Sprays were applied using a Solo backpack sprayer that was equipped with an 8003LP Tee Jet nozzle. The needles were sprayed to the point where the spray just started to drip off them. The amount of fire retardant or water that was applied to each tree was recorded and the trees were allowed to dry for 24 hours prior to setting them up for the test.

To determine the effects the level of care during the display period had on needle and moisture retention, trees were displayed on tree stands with water reservoirs that held approximately 5 quarts of water. A single fire retardant-sprayed and water-sprayed tree was given one of the following six levels of care during the next ten days; the water reservoir was filled daily, the reservoir was refilled every 3 days, the reservoir was refilled every 4 days, the reservoir was refilled half way every 3 days, the reservoir was refilled half way every 4 days, or no water was placed in the reservoir and the tree was displayed dry during the 10-day display period. Thus, there were six treatments (display care), two sub plots (fire retardant and no fire retardant) and four blocks (dates the trees were set up in the display room).

The following parameters were measured during the course of this test; the diameter of the base of each tree, the amount of water and fire retardant applied to each tree, the weight of each tree just prior to application of the fire retardant or water sprays, the daily volume of water consumed by each tree, needle loss, tree quality, and the moisture status of the tree. In addition, at the completion of the test most of the trees were transported to the Western Fire Center where

additional testing was done to determine their fire hazard (See following report). The trees that were not tested at the Fire Center after the 10-day display test was completed were displayed for an additional period of time for use in the second study.

Moisture status - Two methods were used to determine the moisture status of the trees. A pressure chamber was used to measure the ψ of the trees until they dropped below –60 bars. Samples of undamaged current season shoots were also removed from the middle portion of the trees to determine MC [3].

Needle loss - Needle loss was rated when the trees were first set up and then again at the end of the display period. The loss of current season, 1-year-old and 2-year-old needles on two tagged branches on each tree was rated on a scale of 0 to 10, where 0 = none, 1=1 to 10%, 2=11 to 21%, 3 = 21 to 30%,….. and 10 = 91 to 100% needle loss. To determine the extent of needle loss during the display period, the initial needle loss rating was subtracted from the final needle loss rating.

Tree quality and fire retardant damage - Tree quality was on a scale of 1 to 5, where 1 = poor, not acceptable, 2 = fair, 3 = good, 4 = very good, and 5 = excellent. Application of the fire retardant damaged the needles on many of the trees. At the end of the test, the extent of damage was rated on a scale of 1 to 4, where 1 = trace (< 1%), 2 = slight (1 –10%), 3 = moderate (11 – 50%) and 4 = severe (>50% of the needles damaged).

Results

There were no statistically significant differences in tree size, stem diameter, initial moisture status, initial needle loss, and initial tree quality ratings at the start of the display test. Stem diameters ranged from 7.8 to 10.8 cm. When the trees were unbaled and set up in the display room, their moisture levels ranged from –11.6 to –13.8 bars. At the time the trees were sprayed with fire retardant or water, the moisture levels had decreased to –23.1 to –25.2 bars. At the start of the 10-day display period, water potentials ranged from to –28.4 to –31.3 bars and moisture contents ranged from 114.9 to 120.5%. At the time the trees were set up in the display room, they had slightly more than half of their 2-year-old needles and over 90% of their 1-year-old and current season needles. Initial tree quality ratings average 4.5 to 4.6

Needle loss

Display care levels and application of the fire retardant had no effect on needle loss during the 10-day display period. The needle loss ratings for current season, 1-year-old and 2-year-old needles for the fire retardant and non-fire retardant trees was 0.2 vs. 0.1, 0.5 vs. 0.3 and 0.8 vs. 0.6 respectively.

Tree quality and fire retardant damage

Fire retardant application and display care had significant effects of tree quality and damage ratings at the end of the 10-day display period. For all the care treatments, the tree quality ratings for the fire retardant trees were significantly lower than the ratings for the trees that were not treated with the fire retardant (1.2 vs. 1.7). The average damage rating for the fire retardant trees was 3.0.

Display care also had a significant effect on tree quality ratings and a small but significant effect on the damage ratings on the fire retardant-treated trees (Table 1). Trees that were on stands that were filled with water each day had the highest quality ratings. Displaying trees on dry stands or stands that were only refilled half full or refilled every four days had the lowest quality ratings. The effects of the display care were most evident on the trees that were not treated with the fire retardant.

Table 1. The effect of display care on tree quality and fire retardant damage ratings at the end of the 10-day display period

Display care	Fire Retardant trees		Non-fire retardant trees	
	Tree Quality[1]	Damage[2]	Tree Quality	Damage
Stands filled daily	1.3 ab[3]	3.5 a	3.1 a	0.0
Stands refilled every 3 days	1.3 ab	2.5 b	2.0 b	0.0
Stands refilled every 4 days	1.8 a	2.5 b	1.8 bc	0.0
Stands refilled half full every 3 days	1.0 b	3.5 a	1.4 bc	0.0
Stands refilled half full every 4 days	1.3 ab	2.5 b	1.0 c	0.0
Stands dry	1.0 b	3.5 a	1.0 c	0.0

[1]Tree quality was on a scale of 1 to 5, where 1 = poor, not acceptable and 5 = excellent.
[2]Fire retardant damaged was rated on a scale of 1 to 4, where 1 = trace ($< 1\%$) and 4 = severe (>50% of the needles damaged).
[3]Numbersin columns followed by the same letter are not significant, P = 0.05, Duncan's multiple range test.

Water consumption

Display care had a significant effect on the overall (fire retardant-treated and untreated trees) number of days that stands had gone dry between refilling and the resulting number of days that trees did not take up any water (Table 2). Trees that were displayed in stands that were only refilled half full every four days had the highest number of days where the stands were dry and the highest number of days where the trees failed to take up any water. There was no difference between refilling the stands every three days and every day, while refilling the stands full every four days or filling them half full every three days resulted in an intermediate number of dry days and days without any water uptake.

Table 2. The effect of display care on the number of days that the stands were dry between refilling and the number of days Douglas-fir trees failed to take up any water

Display care	No. of days dry	No. of days w/o water uptake
Stand refilled half full every 4 days	2.4 a[1]	3.5 a
Stand refilled half full every 3 days	1.6 b	1.9 b
Stand refilled every 4 days	1.0 b	1.1 bc
Stand refilled every 3 days	0.1 c	0.0 c
Stand filled daily water	0.0 c	0.0 c

[1]Numbersin columns followed by the same letter are not significant, P = 0.05, Duncan's multiple range test.

Treating trees with fire retardants had no effect on the volume of water consumed during the 10-day display period. Fire retardant-treated trees consumed an average of 5.7 liters of water per tree or 0.66 liters of water per cm of stem diameter during the test. Trees that were not treated with fire retardant consumed 5.4 liter per tree or 0.63 liters cm of stem diameter.

Display care had a significant effect on the total volume of water consumed by the trees (Table 3). Trees displayed in stands that were filled daily consumed the greatest volume of water, followed by trees in stands that were refilled every three days and trees in stands that were refilled every four days. Trees that were displayed in stands that were only refilled half full every three or four days used the least amount of water.

Table 3. The effect of the level of care given to Douglas-fir Christmas trees on the total volume of water consumed during a 10-day display period

	Liters of water consumed	
Display care	Per tree	Per cm of stem diameter
Stand filled daily	9.5 a[1]	1.05 a
Stand refilled every 3 days	7.1 b	0.84 b
Stand refilled every 4 days	5.3 c	0.62 c
Stand refilled half full every 3 days	3.2 d	0.38 d
Stand refilled half full every 4 days	2.8 d	0.32 d

[1]Numbersin columns followed by the same letter are not significant, P = 0.05, Duncan's multiple range test.

Moisture status of trees

The level of care and application of fire retardant had a significant effect on the moisture status of the trees. Overall, trees that had been sprayed with fire retardant had significantly higher moisture levels than the non-fire retardant treated trees (Table 4).

Table 4. Effect of fire retardant applications to Douglas-fir Christmas trees on their moisture levels at the end of the 10-day display period

Fire retardant applied	ψ (bars)	Percent moisture content
Yes	-32.1 a[1]	99.8 a
No	-48.0 b	63.2 b

[1]Numbersin columns followed by the same letter are not significant, P = 0.05

As expected, display care had a significant effect on the moisture status of the trees at the end of the ten-day display period (Table 5 and Figure 1). Trees displayed in stands that were refilled daily had the highest moisture levels, while trees that were displayed dry had the lowest. The longer the interval between refilling the stand and only refilling the stand half full resulted in drier trees.

Table 5. The effect of display care on the moisture status of the trees at the end of the 10-day display period

	Non-fire retardant trees		Fire retardant trees	
Display care	ψ (bars)	%MC	ψ (bars)	%MC
Stand filled daily water	-30.5 a[1]	105.0 a	-22.0 a	128.3 a
Stand refilled every 3 days	-35.1 ab	103.6 a	-22.5 a	121.0 ab
Stand refilled every 4 days	-45.3 abc	67.0 ab	-28.9 a	108.8 ab
Stand refilled half full every 3 days	-51.5 bc	61.3 ab	-29.3 a	107.5 ab
Stand refilled half full every 4 days	-60.0 c	40.5 bc	-29.8 a	98.0 b
Stand dry	-60.0 c	12.5 c	-60.0 b	35.3 c

[1]Numbersin columns followed by the same letter are not significant, P = 0.05, Duncan's multiple range test.
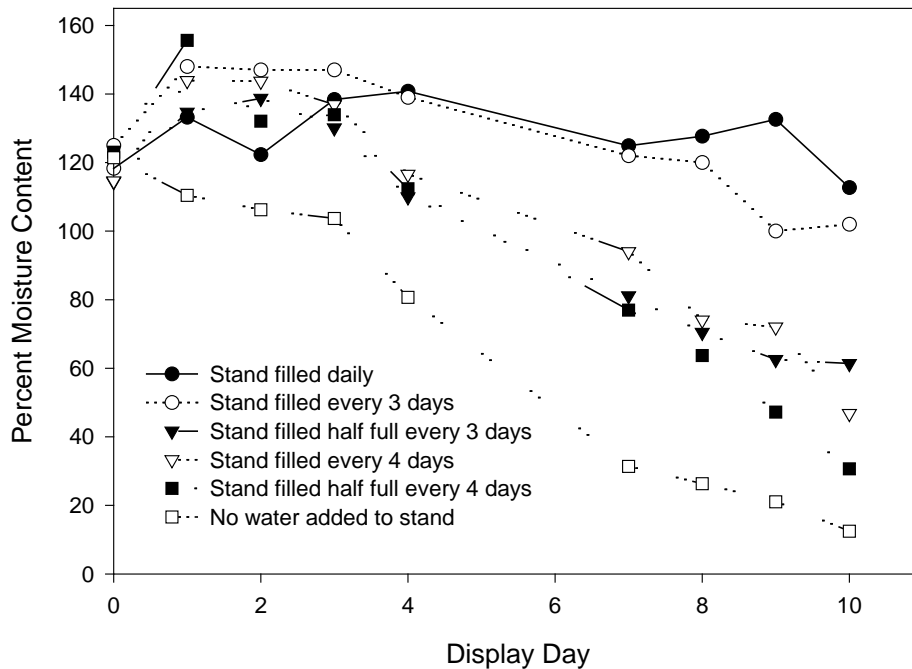
Figure 1. The effect of display care on changes in the moisture content of Douglas-fir Christmas trees during 10-day display test. Data points are the average MC for four trees.

To determine if there was variation in the moisture status based on the locations of where samples were collected, undamaged samples of current season shoots were collected from the top, middle and bottom portions of most of the trees at the end of the 10-day display period. Analysis of this data showed that there was no significant difference in ψ and MC between the different sample locations. Samples from the top, middle and bottom portions of the trees had ψ that averaged -40.3, -40.4 and –40.0 bars respectively and MC that averaged 83.0, 81.6 and 82.6% respectively.

During the course of the test, it became evident that applications of fire retardant damaged the needles on many of the trees. Damaged needles were an olive green to black color and appeared to be very dry compared to the undamaged needles on these trees. Pairs of damaged and undamaged shoots were collected from randomly selected fire retardant-treated trees to determine if there were significant differences in the MC of these shoots. The average MC of the damaged shoots (19.2%) was significantly lower than the MC of the undamaged shoots (110.0%).

Samples were also taken from the outer and inner portions of branches on the fire retardant and non-fire retardant treated trees. On the non-fire retardant trees there were no differences in MC between outer and inner branches (81.8 vs. 74.8%). The shoots from the outer portions of the fire retardant treated trees that were significantly drier (39.2%) than the shoots from the inner portions (101.0%) of the trees.

Flammability

As indicated in the following section of this handout, the flammability of the Douglas-fir Christmas trees used in this study was related to moisture status and the type of ignition source they were exposed to. Details of the flammability testing that were done with the trees used in this experiment will be discussed during the workshop.

Conclusions:

The level of care given to the trees during the 10-day display period had a significant effect on tree quality, water consumption and the moisture status of the trees at the end of the test. Needle loss is often promoted to be an indicator that a tree is dry. Given the limited needle loss that occurred on any of the trees during this test, needle loss does not appear to be a good indicator of the moisture status of Douglas-fir Christmas trees.

When trees were displayed in stands that were watered daily, none of the trees had moisture levels below –34 bars at the end of the test. All of these trees would be expected to fail to burn when exposed to a small flame ignition source. The opposite was true for the trees that were displayed on stands without water. The moisture level of three of the four non-fire retardant trees dropped below –60 bars after only 5 days. By the sixth day, all of these trees were below –60 bars. For the fire retardant-treated trees, one tree dropped below –60 bars after only four days and all the trees were drier than –60 bars after 7 days. All of the trees that were displayed dry would be expected to burn when exposed to a small flame ignition test. Given the low moisture level of some of these trees, they would also be expected have a very high heat release rate. The intermediate levels of care treatments included in this test also resulted in trees that would be expected to burn when exposed to a small flame ignition source. This was particularly true for trees on stands that were only refilled half way or on stands that were only refilled every four days.

In some situations, fire retardants are required to be applied to cut Christmas trees in an effort to minimize potential fire hazards associated with dry trees. In this test, the application of Evergreen Christmas Tree fire retardant damaged the trees. Although the overall moisture levels of the undamaged shoots on the trees that had been treated with the fire retardant was higher than shoots from the non-treated trees, the damaged shoots on the treated trees dried out significantly faster than undamaged shoots. This would tend to negate any benefit associated with the application of this fire retardant. This damage also significantly reduced the quality of the trees. Similar results have been obtained for several other commercially available fire retardants (Chastagner, unpublished). This points out the need to reassess the procedures that are used to currently test potential fire retardants to insure that they are effective and do not have any adverse effects on trees prior to recommending them for use on Christmas trees.

This study confirms the effectiveness and importance of displaying Christmas trees in water as a way of minimizing fire hazards associated with the exposure of trees to a small flame ignition source[6]. In addition, this study also demonstrates the effects the water holding capacity of stands and the level of care given in refilling them has on the ability of consumers to prevent Douglas-fir trees from being a fire hazard when exposed to a small flameignition.

It is important to realize that there are limits on how long it is possible to maintain high moisture levels in trees by displaying them in water. This 10-day study was done in an effort to understand what effects care level had on the moisture and flammability of Douglas-fir trees similar to the

one in the case study. Given that consumers often display trees for several weeks, it is important to realize that the fire hazard of the trees in this study would have increased with additional display time. Douglas-fir trees that are displayed in water can be expected to have moisture levels that are high enough to prevent them from burning as a result of exposure to a small flame for about 3 weeks[5]. After the first week of display, the volume of water Douglas-fir trees consume each day begins to decrease and the trees begin to dry even though they are displayed in water. The moisture level of Douglas-fir trees that are displayed in water typically drops below –60 bars after about 3 weeks. To limit the potential fire hazards associated with cut Christmas trees, consumers who would like to display a tree for 4 to 6 weeks need to make sure that they pick a species such as noble or Fraser fir and then properly care for the tree to insure that the tree continually has water available to it during the time it is displayed indoors.

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V.

The Heat Release Rate Hazard of Christmas Trees

Presented by Vytenis Babrauskas, Ph.D.

Introduction

Burning items which produce a high heat release rate (HRR) are the ones which are most likely to lead to fire injuries or fatalities. This is true not only because of possible thermal injuries, but also because the production of toxic gases is highly correlated to HRR[1,2,3]. In most households, upholstered furniture and mattresses are the combustible items which are likely to produce the highest HRR values. A mattress may produce 500 to 1500 kW (kilowatts), an upholstered chair about the same, while a large sofa may produce 2000 to 3000 kW[4,5]. Other occupant goods, such as bookcases, television sets, dressers, etc., normally show HRR values only a fraction of the above. One exception to consider is Christmas trees.

Several studies examining the HRR of Christmas trees have appeared in the literature. Ahonen and coworkers in Finland tested a fresh-cut tree and two which represented a week's indoor storage. When ignited with a small source, the fresh tree showed around 80 kW HRR, while the others showed about 600 kW[6]. The California Bureau of Home Furnishings tested nine Christmas trees, ignited with a match[7]. Their results also showed that moisture was important, with very dry trees giving 900 - 1700 kW. A fresh-cut tree, however, could not be ignited from small ignition sources.

Test procedures

The Christmas trees were tested in a HRR calorimeter capable of measuring over 10,000 kW. The basic features of the calorimeter are as described in ASTM E 1537 [8]. The tests were run in a large laboratory hall where air supply is effectively unrestricted. Christmas trees are commonly placed in a corner of a room, so to simulate the small amount of radiant heat feedback due to walls, an "open room" was built. Using a floor plan of 2.4 m × 3.6 m (8 × 12 ft), two walls 3.0 m (10 ft) high were erected, as was a ceiling. The remaining two walls were absent, apart from short skirts below the ceiling used to channel the exhaust gases to the collection hood. The walls were made of non-combustible fiber-reinforced cement board. The center of each Christmas tree was located at 0.9 m (3 ft) from each wall, which left a slight clearance in front of the walls. The test Christmas tree was placed on a load platform which allowed a continuous record of mass loss to be obtained. In the HRR calorimeter, smoke and CO and CO_2 production are measured along with the heat release rate. In addition, four radiometers and a large number of thermocouples were installed at various locations.

The trees tested were all Douglas-fir (*Pseudotsuga menziesii*), and were approximately 1.98 m (6.5 ft) tall. As indicated above, the trees were displayed in a simulated living room environment. Various watering programs were used, ranging from displaying trees in stands that were always filled with water to the other extreme of never watering the tree. To systematically examine the effect of watering programs, a majority of the trees were burned following a 10-day display period. These data were supplemented with data from tests with additional trees where the length of the display period and care were varied.

Before each test, the trees were weighed. The weight of the trees ranged from 6.4 kg to 22.4 kg, which was largely due to differences in the moisture content of the trees. Apart from the 22.4 kg specimen (which had a very high moisture content and did not show a high HRR), the next-heaviest specimen was 16 kg. The average weight was 9 kg.

In the formulation of the test program, it was hypothesized that moisture content at the time of burning would be the main controlling variable (in contrast, for example, to the length of time the tree was displayed). Thus, in the study, the moisture content of the foliage was accurately determined. In previous research programs, not enough trees were tested, nor were accurate moisture measurements available in order to delineate the role of moisture. Moisture content was determined by sampling branches, weighing them, then oven-drying them at slightly above 100 C, and weighing them again. Moisture content (MC) is defined as:

$$MC = \frac{Mass_{wet} - Mass_{dry}}{Mass_{dry}} \times 100$$

Note that since the definition uses the dry mass in the denominator, moisture content can easily exceed 100%. When possible, water potential measurements were also taken using a pressure chamber.

In most U.S. households, there will be a significant amount of additional combustibles associated with Christmas trees—decorations of various sorts, wrappings at the base, and gift packages. In the tests described here, no tree decorations were used. At the base, however, a representative collection of gift boxes was located. The boxes were cardboard and had customary Christmas wrappings and ribbons. Most of the boxes contained a small amount of tissue paper and no other combustibles. Two toys, a plastic truck and a stuffed animal (HRR peak = 6 kW) were the only non-packaging fuel included. The packages were arranged in an identical manner around the base for each test.

Three tests were run without packages and two other tests were run without the simulated walls to determine the effect, if any, these items had on the fire development.

To start the fire, in each case the procedure specified by the California State Fire Marshal for fire testing of Christmas trees (a Bunsen burner with a 38 mm high flame; time of application = 12 s) was first applied to a branch about halfway up the tree. The burner simulates a small flame source such as a cigarette lighter. If the tree would not ignite from this source, then the same flame was applied to a gift package below the tree or to a stuffed toy located in the tree.

Results

Photographs of test results are shown in Figures 1 through 7. The first quantitative aspect that was determined in these tests was the moisture content needed for the California test burner, applied directly to the tree, to cause ignition of the tree. The results indicated that MC=50% was a suitable demarcation between trees that ignited from this source and ones that did not. Out of 48 trees tested, only 3 failed to obey this rule, with one test being inconclusive. For the trees that did not ignite from the small flame, *all* ignited from the burning gift-package assembly or stuffed toy. The gift-package assembly, when tested by itself, showed peak HRR values of 98 – 118 kW, with four replicates being tested. Thus, its own HRR was insignificant compared to that of a tree. Visual observations indicated the process of ignition in the cases where the gift packages ignited the tree. The packages burn at a moderate but steady rate, and the fire effectively circles around

the base of the tree. The hot combustion products go up and this has the effect of progressively drying out the tree branches. By the time the packages have stopped burning, the branches are dry enough so that they catch fire and burn.

Figure 1 An example tree ready for testing. All test trees included gift packages under the tree and a single stuffed toy animal in the middle of the tree. Ignition was by small flame to a branch; or by small flame to stuffed toy; or by small flame to gift packages. No tree failed to burn from at least one of these ignition locations.

Figure 2 Fierce burning from a dry (MC = 11%) tree. Peak HRR = 2700 kW.

Figure 3 Post-fire condition of tree shown burning in the previous figure.
Only the main trunk remains.

Figure 4 A rapidly burning tree will ignite nearby combustibles. Here
nearby fabric targets are shown being ignited.

Figure 5 This Christmas tree would not burn when a small flame was applied to a tree branch. Applying the same flame to a small stuffed animal hung on the tree ignited the toy and the tree. Peak HRR = 525 kW.

Figure 6   A fire-retardant tree burning. Some FR specimens generated a great deal of mist.

Figure 7 This FR-treated tree burned vigorously and essentially burned up completely.
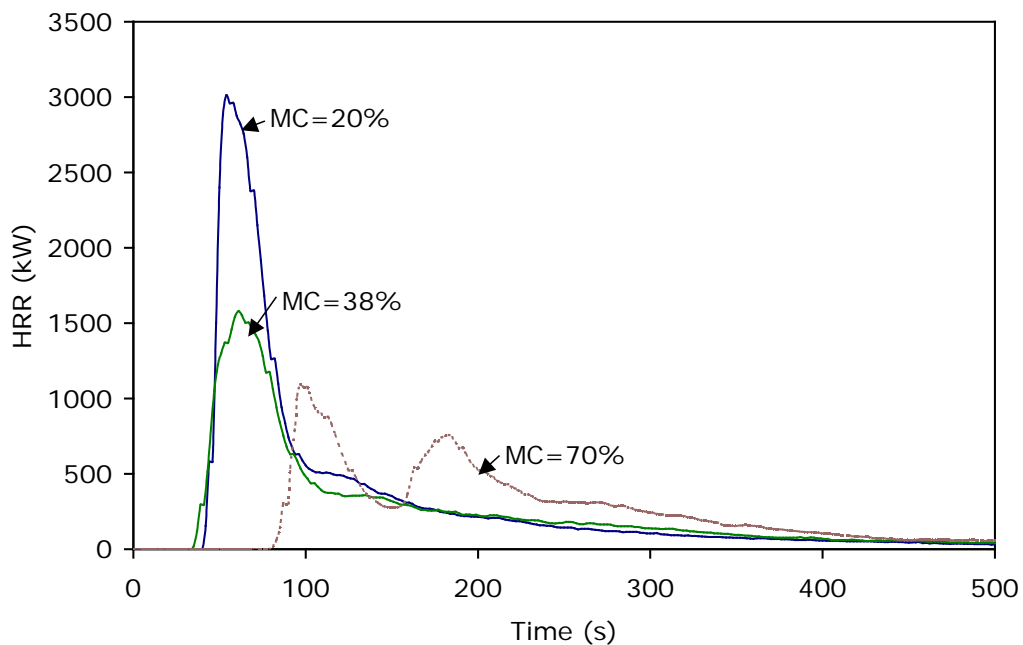

Figure 8 Example HRR curves at several moisture levels

Figure 8 shows the HRR curves for three tests. The MC=20% and MC=38% specimens were ignited by the small flame burner placed next to a branch. It can be seen that there is about 50 s before any detectable HRR occurs, but after that point the burning is exceedingly fierce. In about 1 minute the tree is essentially burned up, only minor burning is going on after that point. The trunks and the large branches never burned up in these tests, although in a room fire other items

would likely contribute to the fire and this would generally cause even these members to be consumed. In the tests reported here, about 1/4 to 1/3 of the mass of each tree remained unburned. The specimen of MC=70% showed a distinctly different behavior. It took about 80 s before there was significant HRR. Again about 2/3 to 3/4 of the mass was consumed for the package-ignited trees, but their time history was much slower. They typically showed a curve with two or more "humps" and the time required for the bulk of the tree to be burned was about 300 – 500 s, instead of 80 s. The moistest package-ignited tree tested had a MC=154%. This tree showed a peak HRR of 444 kW, which is still a sizeable fire. Even this tree lost 60% of its mass during the test. Because MC data were available for each tree, a relation between MC and peak HRR could be found. This is shown in Figure 9. As with any other biological entity, there is significant scatter. However, two trends are very clear: (1) Increasing moisture content decreases the peak HRR; and (2) none of the trees are "non-burning," nor even of negligible fire hazard if ignited with a large ignition source. The dotted line shown in the figure represents an equation which can be used for predictive purposes:

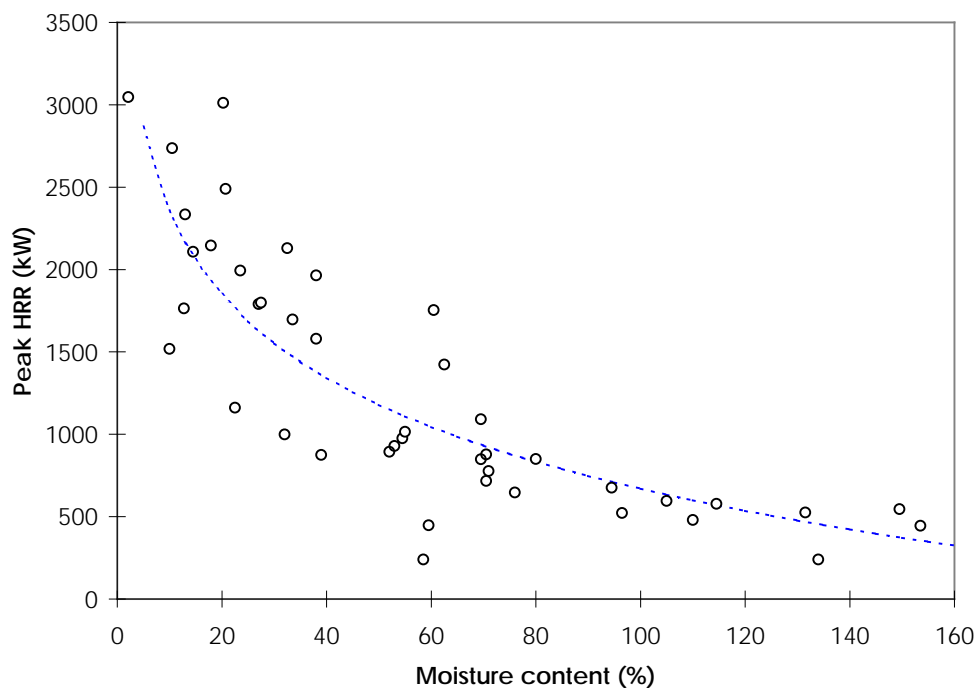$$HRR = 4050 - 734\ln(MC)$$

where "ln" denotes the natural logarithm.

Figure 9 The relation between MC and HRR for non-FR trees

Conclusions

Christmas tree fires are well-documented in fire-incident investigations and have the potential for highly catastrophic results. For example, there is a detailed report from FEMA[9] concerning a Christmas tree fire that killed seven people. Some experimental data is available from previous laboratory studies, but these were limited and did not explore a wide range of treatments, nor did they quantify the effect of moisture content. The present study shows that trees below 15% MC will give HRR values in the range of 2000 to 3000 kW. These values pertain to a common tree height of 1.98 m. Taller or shorter trees can be expected to give proportionately different results.

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The test results confirmed that moisture content (apart from tree species and tree height, which were not tested) was the main variable governing the burning characteristics. The length of the display period and the quality of the watering regimen both serve to determine the moisture content, with the moisture content then being the variable directly controlling the heat release rate.

Douglas-firs with MC more than 50% were found unlikely to be directly ignited from small flames. However, such small ignition sources can readily ignite gift-wrapped packages, and this secondary ignition can then result in a serious tree fire. Defective lights or electrical cords are the most commonly reported ignition sources associated with Christmas trees fires. The arcs that occur in the failure of such devices are physically quite small, but an electrical fault may preheat combustibles in the vicinity of the fault, prior to overt arcing occurring. This ignition mechanism has not been studied in our work, but deserves to be investigated in some detail.

It is normally estimated that a small room can be driven to flashover[10] by a fire of about 1500 kW, if ventilation is through a single open doorway. This type of calculation is easier to perform for a bedroom than for a living room, where complex, interconnected spaces are often involved. Nonetheless, HRR values of the kind documented here represent a highly significant hazard, since, in actual houses, Christmas trees are unlikely to be adjacent to cement board surfaces. Instead, combustible curtains, chairs, sofas, and other items will likely be close by, and these can be expected to readily ignite from the kinds of fires that have been documented here.

Good and prudent advice is frequently given to consumers to keep their Christmas trees well-watered. This is essential, since if tree basins are allowed to run dry, moisture levels drop. None of the trees that were continually displayed in water during these test burned when exposed to the small flame ignition source. However, it is not uncommon for trees to be displayed for much longer periods of time than were used in these tests. Trees are commonly bought a few days after Thanksgiving and may not be taken down until Epiphany, a time span of about 6 weeks. Based on previous postharvest studies, Douglas-fir would not be expected to be able to maintain a high moisture level for this length of time even if it was displayed in water. Other species of Christmas trees, such as noble fir or Fraser fir that are able to maintain high moisture levels for extended periods of time would be much better suited for use under these conditions. This in part probably explains why these species are now the most commonly purchased Christmas tree on the market.

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Video schedule

#1: Test 2-W   114% MC   578 kW   Presents
#2: Test 3-D   7% MC   1628 kW   CSFM flame
#3: Test 27-13   53% MC   929 kW   CSFM flame
#4: Test 30-1   153% MC   444 kW   Presents
#5: Test S15-12   2% MC   3047 kW   CSFM flame
#6: Test 8-3H (FR)   30% MC   786 kW   Presents
#7: Test 5-D (FR)   19% MC   2902 kW   CSFM flame
#8: Brady flocked
#9: Brady unflocked
#10: Brady unflocked (40 kW burner)