PRELIMINARY EVALUATION OF THE FLAMMABILITY OF NATIVE AND ORNAMENTAL PLANTS WITH THE CONE CALORIMETER

Robert H. White, Supervisory Wood Scientist
USDA, Forest Service, Forest Products Laboratory, Madison, WI 53705

David R Weise, Supervisory Research Forester, USDA, Forest Service,
Forest Fire Laboratory, Riverside, CA 92507

Susan Frommer, Partner, Plants for Dry Places, Menifee Valley, CA 92584

INTRODUCTION

As we continue to build more homes in the wildlands where forest and grassland fires occur, the need to find ways to reduce the resulting destruction of homes continues. The destruction of homes in these areas known as wildland/urban interface or intermix is a major fire problem in the United States. The 1995 fires in Long Island, New York, reminded us that such fires are not just a problem in California. The extensiveness of the destruction possible in wildland/urban interface fires has resulted in very large property losses.

The survival of a home during a fire in the wildland/urban intermix areas depends on many factors. These Factors include the intensity of the wildland fire, the access and availability of fire servce protection, topography of the home site, construction characteristics of the home, the landscape immediately around the home, and the weather. By having the correct information homeowners can take action to improve the likelihood that their home will survive a wildland/urban intemix fire (National Fire Protection Association 1991). The homeowner is often given the advice to minimize or eliminate the use of highly flammable vegetation when landscaping their home. The objective of this study was to improve the reliability and scope of information on the relative flammability of native and ornamental plants that could be used to landscape a home.

Standard test methods determine the relative fire performance of building materials. In an attempt to improve the information on plants, we reviewed the test methods of building materials. A recent development in the testing of building materials is the determination of the heat release rate of the material when subjected to a known fire exposure. The test method that currently is most accepted for measuring heat release rate is the cone calorimeter, which uses oxygen consumption to obtain the heat release (Babrauskas 1984), and is an ASTM (1994) and ISO (1993) standard test method. This paper is a progress report on our use of the cone calorimeter to evaluate the flammability of native and ornamental plants. These cone calorimeter tests are part of a larger project in which we propose to determine how well these calorimeter test results relate to tests involving entire shrubs (minus roots).

LITERATURE REVIEW

Although national and international standards have been developed for building materials and furnishings, standard testing procedures have not been devised for vegetation. The ability of native and exotic species planted in and adjacent to chaparral to provide for fire protection and erosion control has been studied for more than 60 years (Radtke 1978, 1981). Work to identify slow-burning plants was performed beginning in the 1950s (Ching and Stewart 1962). Fire-retardant plants, such as rock rose *(Cistus* spp.) and saltbush *(Atriplex* spp.), were identified (Cheo and Montgomery 1970, Montgomery and Cheo 1970). A joint effort between Los Angeles County and the USDA Forest Service resulted in the identification of low flammability plant species to be used in fuelbreaks (Nord and Green 1977). Low flammability plants were defied as shrubs with low levels of fuel volume.

Anderson (1970) described different aspects of vegetation flammability as (1) ignitability, the time required to ignition, (2) sustainability, the ability of vegetation to burn with or without an external heat source, and (3) combustibility, a measure of the rapidity at which the vegetation burns. Martin et al. (1994) extended Anderson’s (1970) study to include a 4th category consumability – a measure of the amount of vegetation that burns. Various chemical and physical methods of describing vegetation flammability have been utilized Thermogravimetric analysis and differential thermal analysis have been used to identify ignition temperatures and heat yields from combustion (Browne and Tang 1962, Philpot and Mutch 1968). Silica-free mineral content has also been proposed as an indicator of vegetation flammability, because the retardant mineral content tends to inhibit the combustion process (Mutch and Philpot 1970). Another technique, the Limiting Oxygen Index, was proposed as a measure of flammability (Mak 1988). None of these tests incorporated the effect of vegetation structure on flammability.

In response to recent wildland/urban interface fires in California the Fire Safety Science Group at University of California–Berkeley has conducted studies examining (1) combustibility of juniper *(Juniperus sabina* var. *tamariscifolia)* and (2) ignitability of juniper by embers. Maximum heat release rates for juniper ignited with a natural gas flame ranged from 160 to 2100 kW and fuel moisture content was linked to maximum heat release ($R^2 = 0.68$) (Schroeder et al. 1994, Stephens et al. 1994).

Other recent work has focused on analytically modeling heat and mass transfer processes that occur in moist woody fuels prior to ignition. Radiant heating in fuel elements was modeled and measured empirically. Initial moisture content was found to be closely linked to time to ignition. The theoretical model can be used to predict time to ignition for woody fuels exposed to radiant heating with some success (Mardini 1993). Live fuels were observed to behave differently than moist dowels, a difference attributed to the presence of bark and other physical characteristics. Ignition temperatures of chamise *(Adenostoma fasciculatum* H. & A.), ponderosa pine *(Pinus ponderosa* Dougl. ex Laws), mountain mahogany *(Cercocarpus betuloides* Nutt. ex T. & G.), incense cedar *(Calocedrus decurrens* (Torr.) F1orin.), and white fir *(Abies concolor* (Gord. & Glend.) Lindl.) wood were found to be approximately 550°K (Mardini and LaVine 1995). This research examined solid wood and did not consider the effects of foliage on flammability.

Flammability of several species in the Mediterranean climates in Europe has been examined using methodology similar to that proposed below (Delabraze and Valette 1981). Time to piloted ignition of small samples (1 g) was examined with a radiant heater. Combustibility of larger vegetation complexes (litter, herbs, and shrubs together) was examined in a wind tunnel facility. Based on the small-scale tests, several tree and shrub species were rated. However, correlations between the small- and large-scale tests were not provided.

METHODS

The cone calorimeter testing conducted in our study so far includes an initial test series of four species and the first of four series of tests on 10 species of plants. The additional three series of tests will be conducted during the next year to investigate the seasonal effect on fire behavior. We hope to correlate the small-scale tests with large-scale tests this year.

Materials

In the initial series of tests, the samples came from the following plants:

Chamise	*(Adenostoma fasciculatum* H. & A)
California sagebrush	*(Artemisia californica* Less.)
Brittlebush	*(Encelia farinosa* Gray ex Torr.)
California scrub oak	*(Quercus dumosa* Nutt.)

In the series of tests on 10 species, the samples came from the following species:

Chamise	*(Adenostoma fasciculatum* H. & A.)
Aloe	*(Aloe* sp.)
Saltbush	*(Atriplex halimus* L.)
Wild lilac	*(Ceanothus* “Joyce Coulter")
Crimson-spot rockrose	*(Cistus ladanifer* L.)
Sageleaf rockrose	*(Cistus salviifolius* L.)
Toyon	*(Heteromeles arbutifolia* M. Roem.)
Prostrate myoporum	*(Myoporum parvifolium* “Putah Creek”)
Olive	*(Olea europaea* L.)
No common name available	*(Rhagodia spinescens)*

Rhagodia spinescens is an Australian plant. Samples of the plants were obtained from Plants for Dry Places (Menifee Valley, CA) by the USDA Forest Service Fire Laboratory in Riverside, California, and were shipped overnight to the USDA Forest Service, Forest Products Laboratory (FPL), in Madisou Wisconsin. The green and dried branch samples with intact foliage were collected from the outer crown of each species with new growth, flowering, and fruiting portions removed. The diameters of the branch samples were 6 mm or less. We kept the plastic bags of green samples in cold storage until testing to retain moisture content. Desiccant was added to the plastic bags with the dried samples.

Equipment

The cone calorimeter obtains the heat release rate by measuring the consumption of oxygen as a result of combustion. An electric cone heater exposes the 100 by 100 mm specimen holder to a fixed heat flux in an open environment. In these tests, the plant specimens were placed in an aluminum foil container that was laid on a holder with a low density ceramic wool blanket. To contain the pieces of the specimens, we placed a steel edge retainer frame with a grid over the holder. With the edge frame, the exposed surface area was 0.008836 m^2. This horizontally oriented specimen was placed on a load cell beneath the cone heater. In these tests, we used a water-cooled shutter to shield the specimen until the test was initiated. An electric spark igniter provided the ignition source. The cone calorimeter at FPL is an Atlas Electric Devices Company CONE2 AutoCal Combustion Analysis System.[1]

Combustion gases were collected in an exhaust hood and duct. Samples of the gases were analyzed for their oxygen, carbon dioxide, and carbon monoxide contents. From these gas concentration measurements, the heat release as a result of combustion was calculated. Initial test data were curves of heat release rate versus time and curves of mass loss rate versus time. Heat release rate is normally expressed as kW per exposed surface area (m^2). From the visual observations and these initial test data, results that can be reported included the following: peak heat release rate at time x, average heat release rate over interval y minutes after ignition, total heat release, average mass loss rate, time for sustained ignition, effective heat of combustion versus time, and average effective heat of combustion. Effective heat of combustion is heat release per unit mass loss.

Procedures

Samples were removed from the plastic bags, weighed, and placed in the holder immediately prior to testing. The amount of material was usually a single layer of foliage with the entire exposed surface area of the sample holder not covered. In the initial series of tests, the specimens were tested at three different flux levels (one replicate at 20 kW/m^2, two replicates at 35 kW/m^2, and one replicate at 50 kW/m^2). For the current series of tests, we are testing three replicates of the green and ovendried samples at 25 kW/m^2 and one replicate of the green samples at 50 kw/m^2. Gas concentration and mass loss measurements were taken at l-second intervals. A small orifice plate was used in the exhaust duct to obtain a measured exhaust flow of 0.012 m^3/s.

---

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

RESULTS AND DISCUSSION

Results for the initial group of four species indicated measurable differences in the fire behavior of the plant specimens (Table 1). The differences among the four species depended on the heat flux used in the tests. At the 20 kW/m^2 exposure, the heat release rates for the chamise and sagebrush were significantly greater than that for the brittlebush or scrub oak. In a listing of plants, chamise and sagebrush were identified as highly flammable (Baptiste 1992). At 35 kW/m^2 exposure, the heat release rate for the scrub oak was much greater than at 20 kW/m^2 and was the highest of the four species. At 50 kW/m^2 exposure, there was a further increase in the heat release rate for the brittlebush sample compared with the results for the lower heat flux levels. The average moisture contents (dry weight basis) were 107, 131, 107 and 227 percent for the chamise, sagebrush, scrub oak, and brittlebush samples, respectively. The low heat release rate and effective heat of combustion for brittlebush probably reflect its high level of moisture content. Based on these results, it was decided to go forward with the study and test three replicates at 25 kW/m^2 and one replicate at 50 kW/m^2.

Table 1. Results for initial tests of four species.

Species	Initial Mass	Avg. Heat Release Rate, 60 s.	Peak Heat Release Rate	Time for Peak Heat Release Rate	Effective Heat of Combustion
	g	kW/m^2	kW/m^2	s	MJ/kg
20 kW/m^2 Incident Flux					
Brittlebush	15.6	2	11	533	1.3
Sagebrush	7.2	39	68	211	5.2
Chamise	25.3	94	127	579	5.1
Scrub oak	6.6	2	14	457	2.8
35 kW/m^2 Incident Flux					
Brittlebush	17.3	14	28	439	2.1
Sagebrush	5.9	34	45	301	6.4
Chamise	19.1	50	91	101	6.1
Scrub oak	7.1	51	101	155	6.8
50 kW/m^2 Incident Flux					
Brittlebush	18.2	41	52	286	3.5
Sagebrush	4.6	32	57	77	6.7
Chamise	19.7	69	96	164	6.8
Scrub oak	6.9	45	87	90	6.0

The results for the first series of tests on the 10 species again showed distinct differences in heat release rate between some of the species (Tables 2-3). These results are averages for the one to thee replicates. For the green samples exposed to 25 kW/m^2, the coefficients of variation for the peak heat release rates (three replicates) ranged from 8 to 72 percent (mean of 32 percent). For the ovendry samples, the coefficients of variation ranged from 5 to 25 percent (mean of 11 percent). Olive and chamise had the higher rates of heat release. Because the plant samples were not conditioned, the differences between results for Chamise in Table 1 and Tables 2 to 4 likely reflect seasonal differences, such as the moisture content of the plants as received. The moisture content data for these tests are not yet available. The green aloe was the lowest in rate of heat release. The general rankings of the plants in Tables 2 to 3 are consistent with the list in Baptiste (1992). As previously noted, chamise is know as a highly flammable plant. The following plants are considered to have some fire resistance: saltbush, rockrose, toyon, aloe, and myoporum (Baptiste 1992). Data not listed in Table 2 reflect problems in observing sustained ignition with the small green samples. Values for average effective heat of combustion (Table 4) are the total heat release divided by the total mass loss (including moisture loss).

Table 2. Average heat release rates for 1 minute after ignition of plant specimen.

Species	Average Heat Release Rate 60-s interval		
	25 kW/m^2 Incident Flux		50 kW/m^2 Incident Flux
	Green	Ovendry	Green
	kW/m^2		
Olive	78	161	145
Chamise	76	161	79
Wild Lilac	25	72	-
Toyon	14	93	48
Crimson-Spot Rockrose	4	72	-
Sageleaf Rockrose	30	41	57
Prostrate Myoporum	20	97	-
Saltbush	12	46	-
Rhagodia spinescens	2	20	-
Aloe	-	63	-

Table 3. Peak heat release rates for the various plants.

Species	Peak Heat Release Rate		
	25 kW/m^2 Incident Flux		50 kW/m^2 Incident Flux
	Green	Ovendry	Green
	kW/m^2		
Olive	127	258	196
Chamise	102	246	156
Wild Lilac	55	138	68
Toyon	55	111	52
Crimson-Spot Rockrose	52	151	67
Sageleaf Rockrose	47	99	48
Prostrate Myoporum	34	161	33
Saltbush	26	73	28
Rhagodia spinescens	34	87	19
Aloe	4	92	6

Table 4. Effective heats of combustion for the various plants.

Species	Effective Heat of Combustion		
	25 kW/m^2 Incident Flux		50 kW/m^2 Incident Flux
	Green	Ovendry	Green
	MJ/kg		
Olive	8.8	19.1	12.1
Chamise	7.7	18.2	9.1
Wild Lilac	4.1	14.8	5.1
Toyon	3.8	17.0	5.5
Crimson-Spot Rockrose	7.6	16.1	6.6
Sageleaf Rockrose	5.1	14.0	4.9
Prostrate Myoporum	1.8	17.9	2.7
Saltbush	2.4	14.0	3.0
Rhagodia spinescens	2.9	14.7	1.7
Aloe	.04	12.8	0.5

Cone calorimeter testing is normally done on an exposed surface area basis. This is difficult when the specimen is pieces of foliage. Generally, the foliage did not completely cover the exposed surface area of the holder. In the case of aloe, the sample was a thick bed of foliage. The initial mass of the green samples ranged from 4 g for the *Rhagodia spinescens* to 87 g for the aloe. The initial mass for the ovendry samples ranged from 1.4 g for *Rhagodia spinescens* to 15 g for Toyon. This raised the question whether the results should be divided by initial mass to correct for this variation. A series of tests of green samples of Toyon were conducted with a range of initial mass (Table 5). Results indicate that the initial mass mainly has an effect on the time for the peak heat release rate, the time for sustained ignition, and the total heat release. Each of these results increased with larger initial mass (R^2= 0.9). The initial mass did not appear to affect the peak heat release rate. For the average heat release rate, the result for the 40-g sample was greater than those for the other samples. In both the 30-g and 40-g samples, the foliage completely covered the aluminum foil. For the 2.6-g sample, about 50 percent of the foil was exposed. The effects of characteristics, such as total surface area and the surface area to fuel volume ratio, on these test results will be examined.

Table 5. Tests of green Toyon samples with different initial masses at 25 kW/m^2 heat flux.

Measurement	Units	Results					
Initial Mass	g	2.6	5.6	7.2	16.7	30.0	40.1
Avg. Heat Release Rate	kW/m^2	-	50	59	48	60	83
Peak Heat Release Rate	kW/m^2	60	109	82	85	77	93
Time for Peak Heat Release Rate	s	87	162	115	391	633	882
Total Heat Release	MJ/m^2	2.0	3.8	6.1	10.5	18.2	21.3
Ignition Time	s	-	154	104	370	554	849
Effective Heat of Combustion	MJ/kg	6.2	6.0	7.6	6.1	6.1	5.6

Although the cone calorimeter appears to be able to differentiate the vegetation, questions remain about the application of the data to the overall flammability of the vegetation. The tests of whole plants planned as part of the overall project need to be conducted. As noted in the literature review, some plants have desirable fire behavior as a result of their low volumetric fuel value rather than a slow burning rate. The results obtained in the cone calorimeter need to be further interpreted in terms of the different aspects of vegetation flammability described by Anderson (1970).

The results presented in this paper are preliminary. During the next year, we will test samples of the 10 plants three more iimes. Additional research needs to be done on test parameters, such as sample preparation, that may reduce consistency in the results or affect the application of the results to natural fires.

CONCLUSIONS

Initial results from the cone calorimeter evaluation of native and ornamental plants support its use as a method to evaluate relative flammability of these plants. Further work needs to be done to improve consistency in the results and on the application of the data to natural fires.

LITERATURE CITED

ASTM. 1994. Standard test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter. Designation American Society for Testing and Materials E-1354. Philadelphia, Pa.

Anderson, H.E. 1970. Forest fuel ignitibility. Fire Technology 6(4): 312–319.

Babrauskas, V. 1984. Development of the cone calorimeter—a bench scale heat release rate apparatus based on oxygen consumption. Fire and Materials 8: 81–95.

Baptiste, Linda. 1992. Firescape–Landscaping to reduce fire hazard. Oakland, CA: East Bay Municipal Utility District. 16 p.

Browne, F.L. and W.K. Tang. 1962. Thermogravimetric and differential thermal analysis of wood and of wood treated with inorganic salts during pyrolysis. Fire Research Abstracts and Reviews 4(1&2): 76–91.

Cheo, P.C. and K.R. Montgomery. 1970. The study of fire-retardance in plants. Lasca Leaves 20(3): 52–56.

Ching, F.F.T. and W.S. Stewart. 1962. Research with slow burning plants. J. Forestry 60(11): 796–798.

Delabraze, P. and J.-Ch. Valette. 1981. The use of fire in silviculture. *In:* Dynamics and Management of Mediterranean-type Ecosystems. 1981 June 22–26, San Diego, CA.

International Organization of Standards. 1993. Fire tests—Reaction to Fire. Part 1: Rate of heat release from building products (Cone Calorimeter Method). Designation ISO 5660-1. Geneva, Switzerland: ISO.

Mak, E.H.T. 1988. Measuring foliar flammability with the Limiting Oxygen Index method. Forest Service 23(2): 523–529.

Mardini, J.A. 1993. Experimental and analytical study of heat and mass transfer in wood prior to ignition in fires. Ph.D. Dissertation, University of California, Los Angeles. 244 p.

Mardini, J.A. and A.S. Lavine. 1995. Effects of species and green wood moisture variation on its time to ignition during fires. Final report, USDA Forest Service Coop Agreement PSW–94–004CA. Pacific Southwest Research Station, Albany, CA. 19 p.

Martin, R.E., D.A. Gordon, M.A. Gutierrez, and others. 1994. Assessing the flammability of domestic and wildland vegetation. *In:* 12th Conference on Fire and Forest Meteorology, 1993 Oct. 26–28, Jekyll Island, Ga. Pub. 94-02, Society of American Foresters, Bethesda, MD. 796 p.

Montgomery, K.R. and P.C. Cheo. 1970. Fire-retardant plants for brush fire prevention in hillside residential areas. Lasca Leaves 20(3) 56–58, 67.

Mutch, R.W. and C.W. Philpot. 1970. Relation of silica content to flammability in grasses. Forest Science 16(1): 64–65.

National Fire Protection Association. 1991. Protecting your home from wildfire. NFPA, Quincy, MA. 24 p.

Nord, E.C. and L.R. Green. 1977. Low-volume and slow-burning vegetation for planting on clearings in California chaparral. PSW–RP–124. U.S.Department of Agriculture, Forest Service.

Philpot, C.W. and R. W. Mutch. 1968. Flammability of herbicide-treated guava foliage. INT–RP–54. U.S.Department of Agriculture, Forest Service.

Radtke, K.W.H. 1978. Wildland plantings: native and exotic. 1911–1977. County of Los Angeles, Dept. of Forester and Fire Warden, Forestry Division. 135 p.

Radtke, K.W.H. 1981. Living more safely in the chaparral-urban interface. PSW–GTR–67. U.S.Department of Agriculture, Forest Service.

Schroeder, R.A., R.E. Martin, and M. Chambers. 1994. A method for measuring ember ignitability of domestic vegetation. *In:* 12th Conference on Fire and Forest Meteorology, Oct. 26–28, 1993, Jekyll Island, Ga. Pub. 94-02, Society of American Foresters, Bethesda, MD. 796 p.

Stephens, S.L., D.A. Gordon, and R.E. Martin. 1994. Combustibility of selected domestic vegetation subjected to desiccation. *In:* 12th Conference on Fire and Forest Meteorology, 1993 Oct. 26–28, Jekyll Island, Ga. Pub. 94-02, Society of American Foresters, Bethesda, MD. 796 p.

PROCEEDINGS OF THE
INTERNATIONAL CONFERENCE ON FIRE SAFETY

VOLUME TWENTY-ONE

1996

PAPERS PRESENTED AT THE

TWENTY-FIRST INTERNATIONAL CONFERENCE ON FIRE SAFETY

CLARION HOTEL

SAN FRANCISCO INTERNATIONAL AIRPORT

MILLBRAE, CALIFORNIA

U.S.A.

JANUARY 8 TO 12, 1996