1.4

LABORATORY AND FIELD STUDY OF PARTICULATE EMISSIONS FACTORS OF PRESCRIBED WILDLAND FIRES

T. Maynard[1], S. Hosseini[1], M. Princevac[1], H. Jung[1], D. Cocker[1], P.Tang[1], X. Tang[1], Q. Li[1], D.R. Weise[2], W.M. Hao[3], R. Yokelson[4], W. Miller[1], S.Mahalingam[5]

1.University of California at Riverside, Riverside, California 92521, 2.USDA Forest Service, Pacific Southwest Research Station, Riverside, California 92507, 3.USDA Forest Service, Rocky Mountain Research Station, 59808 4. University of Montana, Missoula, Montana 59812, 5. University of Alabama in Huntsville, Huntsville, Alabama 35899

1. INTRODUCTION

Prescribed fire, the deliberate burning of wildland areas, is an important tool for natural resource management. Prescribed burns allow the natural fire cycle to be emulated under controlled conditions, helping to preserve ecosystems and reducing wildfire risk by eliminating hazardous vegetation buildup. Unfortunately, prescribed fire is accompanied by undesirable side effects, principally the impact of smoke on local and regional air quality. To address this risk, many state and local governments require an air quality analysis to be performed prior to burning. Currently, the emissions inventories required to estimate the air quality impact of prescribed burns are limited, particularly for chaparral (shrub-type) fuels common to the southwestern United States. One of the primary emissions products of concern in wildland fire smoke is particulate matter of less than 2.5 µm in size ($PM_{2.5}$). $PM_{2.5}$ has been identified as a significant risk to public health (Shusterman et al, 1993). The emission factor (EF), a measure of pollutant production in relation to the amount and type of fuel burned, is the most commonly used quantity to estimate the impact of emissions-generating activities. In this paper, laboratory experiments to determine $PM_{2.5}$ emissions factors for specific species of chaparral fuels are described and compared with emissions factors obtained during a full-scale prescribed burn in southern California.

2. EXPERIMENTAL METHODS

2.1 Laboratory Experiments

Experiments were conducted in the Missoula Fire Sciences Laboratory, at the USFS Rocky Mountain Research Station in Missoula, MT. The laboratory has been widely used for biomass emissions studies (Christian et al, 2003; Chen et al, 2006) and is described in detail Maynard et al (2010).

2.1.1 Sampling Equipment

Sampling equipment was placed on a platform 17 m above the fuel bed, surrounding the main exhaust stack (Figure 1). $PM_{2.5}$ emissions were measured using Teflon filters connected to the stack, as described by Hosseini et al (2009). A size-selective $PM_{2.5}$ cyclone was installed upstream of the filters, and a new filter was installed prior to each burn. Additional instrumentation for the characterization of various gaseous and particulate species was also deployed using additional methods which are beyond the scope of this paper.

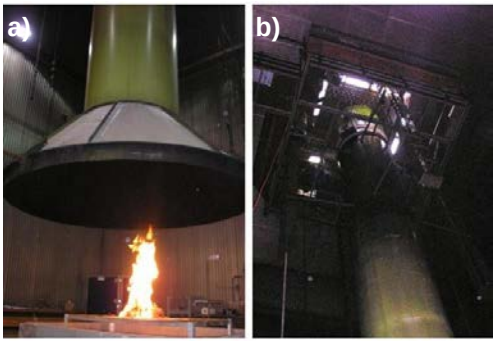

Fig. 1. a) Fire under laboratory flue, b) Looking up at instrumentation platform

*Corresponding author address: Trevor Maynard, Univ. of California, Riverside, Dept. of Mechanical Engineering, Riverside, CA 92521;

e-mail: tmaynard@engr.ucr.edu

2.1.2 Fuels and Fuel Bed

The chaparral fuels used were obtained from the California central coast, and are the most commonly occurring types in the region. Fuels were loaded to simulate their natural arrangement on a 2 m x 1 m fuel bed. Real-time mass loss was obtained using digital load cells. Fuels were ignited using a butane torch and were allowed to burn to completion.

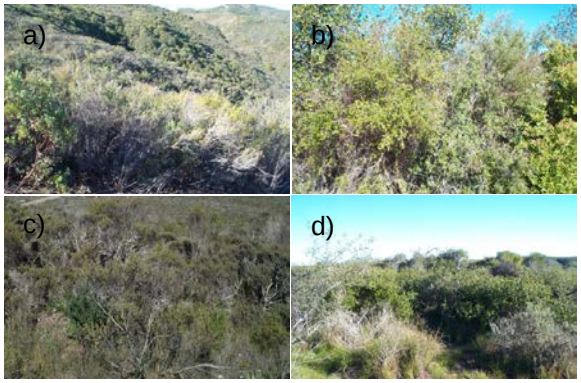

Fig. 2. Selected chaparral fuels a) Chamise/Scrub oak, b) Ceanothus, c) Coastal Sage Scrub, d) Maritime chaparral

2.1.3 Calculation of Laboratory Emissions Factors

Christian et al (2003) defined the emission factor as:

$$\mathrm{EF_X}\ (\mathrm{g\ kg^{-1}}) = \frac{m_X}{m_{burned}} \qquad (1)$$

where EF_X is the emission factor of compound X, m_{burned} is the mass of dry fuel consumed (kg), and m_X is the total mass of pollutant X emitted (g). After each laboratory burn, the mass of $PM_{2.5}$ emitted was determined using the mass deposited on the filter multiplied by the relative amount of flow across the filter:

$$m_x = m_{filter} \times \frac{Q_{duct}}{Q_{line}} \qquad (2)$$

where m_{filter} is the amount of mass deposited on the filter (g), and Q_{line} is the volumetric flow rate through the filter sampling line ($m^3\ s^{-1}$). The emissions factor is then obtained using Eq. (1). Similar methods have been employed to measure particulate emissions of California chaparral in a laboratory setting, as demonstrated by Weise et al (1991).

2.2 Field Experiments

Field measurements were performed during a prescribed burn at Vandenberg AFB in Lompoc, CA in November, 2009.

2.2.1 Site Description

The landscape surrounding the experiment site was characterized by rugged terrain with maritime chaparral and coastal sage as the dominant fuel types (Figure 3). The burn plot was approximately 150 acres with a moderate south-facing aspect.

Fig. 3. Representative terrain and fuels at Vandenberg AFB in Lompoc, CA (near Santa Barbara)

2.2.2 Instrumentation

A truck-based mobile laboratory was used for near-source emissions characterization, and was placed directly adjacent to the burn plot. Instrumentation included the Teflon filters described above, as well as a non-dispersive infrared (NDIR) analyzer to determine CO_2 concentration. Additional emissions characterization instruments were also deployed, but will not be discussed in this paper.

Meteorological conditions were measured at two sites near the burn area. A 10 m tower was deployed approximately 2 km south of the burn and contained two sonic anemometers, a net radiometer, laser photometers (to obtain $PM_{2.5}$ concentration), temperature/relative humidity probes, and soil heat flux sensors. A 3 m tripod was deployed directly adjacent to the burn area, and contained a single sonic anemometer and laser photometer.

2.2.3 Calculation of Field Emissions Factors

Since fuel consumption in the field cannot be reliably determined, it is generally not possible to

use Eq. (1) to determine the emissions factor. However, since the laboratory emissions factor of CO_2 measured by our colleagues was seen to vary over a narrow range (~1750 g/kg), emissions factor of $PM_{2.5}$ can be determined by determining the amount of $PM_{2.5}$ released relative to CO_2:

$$EF(PM_{2.5}) = ER(PM_{2.5}) \times EF(CO_2) \quad (3)$$

where ER is the ratio of $PM_{2.5}$ to CO_2 concentration, and $PM_{2.5}$ concentration was obtained by dividing the mass deposited on the filter by the product of filter flow rate and measurement duration. Emissions factors were determined during four measurement periods of 60 minutes each.

2.2.4 Fire Behavior

Weather conditions at the time of ignition were WNW at 2-5 m/s with a temperature of 19°C and 50% RH. These conditions were not conducive to extreme fire behavior. The fire was ignited from the perimeter by hand. Flame lengths averaged 2-3 m, but sometimes exceeded 5 m in dense fuel stands (Figure 4). Active flaming occurred for approximately 5 hours.

Fig. 4. Typical fire behavior during Vandenberg AFB prescribed burn on 11 November 2009.

3. RESULTS AND DISCUSSION

3.1 Laboratory Experiments

A summary of emissions factors obtained during laboratory experiments is shown in Table 1. These values compare favorably with the measurements of Hardy et al (1996), who measured emissions factors using an apparatus deployed above the flaming front of a field-scale prescribed burn. The measurements of Weise et al (1991) were of smaller scale (sampler height only 1.8 m above fuel bed) and fuel moisture content was high (greater than 50% of dry fuel mass for all fuels).

3.2 Field Experiments

A summary of $PM_{2.5}$ emissions factors obtained during field experiments is shown in Table 2. Because fuels within the burn site were mixed, the values shown represent an average for all fuels. Throughout the burn, the emission factor was seen to increase, except during the last measurement period. The most likely explanation for this is the decrease in combustion efficiency near the measurement location as the burn progressed. Christian et al (2003) illustrated that an inverse relationship exists between combustion efficiency and particulate emissions production. During the first measurement period, fuels near the truck were actively flaming. However, as the burn progressed, the truck began to sample smoke from smoldering (i.e. less efficient) combustion.

5. SUMMARY AND CONCLUSIONS

Experiments to determine $PM_{2.5}$ emissions factors for southwestern chaparral fuels were performed in the laboratory and during a full scale prescribed burn using two different methods. The calculated emissions factors were compared to published values, as well as data obtained for identical fuels using filter methods. The meteorological data obtained during this study is currently being used in computational modeling efforts to study the characteristics and effects of dispersion and pollutant transport from prescribed burns.

Table 1. $PM_{2.5}$ Laboratory emissions factors for selected southwestern chaparral fuels

Fuel type	$PM_{2.5}$ EF ($g\ kg^{-1}$) (This study) [a]	$PM_{2.5}$ EF ($g\ kg^{-1}$) (Literature)
Chamise/Scrub Oak	7.38 ± 2.11	20.05 [b]
Chaparral[c]	5.46 ± 1.31	8.65 ± 0.60 [d]
Ceanothus	4.62 ± 2.08	67.65 [b]
Maritime Chaparral	4.10 ± 0.34	N/A
Coastal Sage	6.36 ± 0.72	47.27 [b]
California Sagebrush	6.87 ± 0.83	N/A
Manzanita	3.61 ± 1.17	87.37 [b]

a. Data represented as mean ± one standard deviation of the mean

b. Data obtained from Weise et al (1991) using glass fiber filters

c. Southwestern chaparral fuel (multiple species)

d. Data obtained from Hardy et al (1996) during field measurements using carbon mass balance method

Table 2. $PM_{2.5}$ Field emissions factors for southwestern chaparral at Vandenberg AFB

Local time	$PM_{2.5}$ EF ($g\ kg^{-1}$)
1100 - 1200	5.27
1215 - 1325	7.57
1335 - 1450	14.13
1505 - 1605	3.49

ACKNOWLEDGEMENTS

The authors acknowledge support for this research through contract SI-1648 from the Strategic Environmental Research and Development Program (SERDP). We are also grateful to the technical staff at the USDA Forest Service Fire Sciences Laboratory in Missoula, MT and the Vandenberg Fire Department.

REFERENCES

D. Shusterman , J.Z. Kaplan, C. Canabarro, West J. Med. (158) (1993) 133-138.

T.J. Christian, B. Kleiss, R. J. Yokelson, R. Holzinger, P. J. Crutzen, W. M. Hao,H. Saharjo, D. E. Ward, J. Geophys. Res., 108 (2003), 4719.

S. Hosseini, Q. Li,, A. Miller, D. Cocker, M. Sharivastava, D. Weise, W. Hao, R. Yokelson, H. Jung , Chemical and Physical Characterization of Wood Smoke under Controlled Conditions. Fall Meeting of the Western States Section of the Combustion Institute, Irvine, CA, 2009

D.R. Weise, D.E. Ward, T. Paysen, A. Koonce, Int. J. Wildland Fire 1 (1991) 153-158.

C.C Hardy, S. Conard, J. Regelbrugge, D. Teesdale, Smoke Emissions From Prescribed Burning Of Southern California Chaparral, Research Paper PNW-RP-85, USDA Pacific Northwest Research Station, 1996.