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Combustion and Flame 144 (2006) 349–359

Combustion and Flame

www.elsevier.com/locate/combustflame

Comparison of burning characteristics of live and dead chaparral fuels ☆

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Received 22 December 2004; received in revised form 10 July 2005; accepted 10 August 2005

Available online 14 October 2005

Abstract

Wildfire spread in living vegetation, such as chaparral in southern California, often causes significant damage to infrastructure and ecosystems. The effects of physical characteristics of fuels and fuel beds on live fuel burning and whether live fuels differ fundamentally from dead woody fuels in their burning characteristics are not well understood. Toward this end, three common chaparral fuels prevalent in southern California, chamise, manzanita, and ceanothus, were investigated by burning them in a cylindrical container. The observed fire behavior included mass loss rate, flame height, and temperature structure above the burning fuel bed. By using successive images of the temperature field, a recently developed thermal particle image velocity (TPIV) algorithm was applied to estimate flow velocities in the vicinity of the flame. A linear regression fit was used to explain the observed time difference between when maximum flame height and maximum mass loss rate occur, as a function of fuel moisture content. Two different methods were used to extract power laws for flame heights of live and dead fuels. It was observed that the parameters defined in the well-known two-fifths power law for flame height as a function of heat release rate were inadequate for live fuels. As the moisture content increases, the heat release rate in the power law needs to be calculated at the time when the maximum flame height is achieved, as opposed to the maximum mass loss rate. Dimensionless parameters were used to express local temperature and velocity structure of live and dead chaparral fuels in the form of a Gaussian profile over different regimes in a fire plume.

Keywords: Chaparral; Mass loss rate; Flame height; Infrared

1. Introduction

Chaparral is a hardy, fire-prone plant community characterized by evergreen sclerophyll shrubs such as chamise (*Adenostoma fasciculatum*), manzanita (*Arctostaphylos glandulosa*), and hoaryleaf ceanothus (*Ceanothus crassifolius*). Often, two or more species are found interspersed with other shrubs (Fig. 1a). Manzanita and ceanothus are species with leaves that

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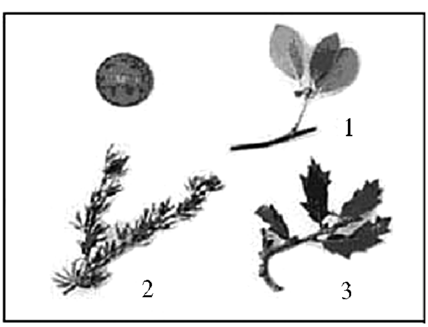
0010-2180/$ – see front matter
doi:10.1016/j.combustflame.2005.08.008

(a)

(b)



(c)

Fig. 1. (a) Chaparral is a mixture of several different species of shrubs that grows in the Mediterranean climate of California. (b) Litter and dead grass. (c) Foliage and fine branch samples of three chaparral species used in the fire plume experiment: (1) manzanita (*Arctostaphylos parryana*), (2) chamise (*Adenostoma fasciculatum*), and (3) hoaryleaf ceanothus (*Ceanothus crassifolius*). Coin diameter is 1.9 cm.

are generally ovoid in shape; however, manzanita leaves are thicker than those of ceanothus. Chamise shrubs range in height from 1 to 3 m with leaves that are linear in shape (Fig. 1c). Fuel depths observed in chaparral crowns (area occupied by branches and foliage) range from 30 to >120 cm, and the crowns tend to be fairly porous (low packing ratio). Surface fuels such as litter and dead grass are often sparse (Fig. 1b). Fire spread in chaparral often occurs in the crowns leading some to describe fires in this vegetation type as a crown fire.

Fire burns large areas in living chaparral fuels in southern California annually [1]. The ability to predict fire spread in these fuels is limited by the fact that current fire-spread models were designed primarily for dead fuels and only a limited set of experimental data exist for testing models. This problem has been recognized for 60 years [2,3]. Recently, in Europe and Australia, modeling of fire spread in various live fuels has occurred [4–8], and in the United States, there are limited empirical and modeling tools to predict fire spread in live fuels [9–19].

Rothermel's [20] semiempirical fire-spread formulation forms the basis of current computer-based operational models utilized in the United States, including BEHAVE [21] and FARSITE [22]. It is applicable for fuel beds dominated by dead fuel. However, fuel moisture has long been recognized as having a major influence on the ignition, development, and spread of fires [23]. The moisture content of a fuel is the mass of water in that fuel, expressed as a percentage of the oven-dry weight of that fuel. Thus, if the fuel were totally dry, then the fuel moisture content would be zero. That being said, when a fuel has less than 30% moisture content, it is basically a dead fuel and is treated as such. In the case of living fuels, moisture content ranges from 30 to around 300%. The moisture content of dead fuels responds quickly to changes in relative humidity and temperature, whereas the moisture content of live fuels depends largely on physiological activity within the vegetation and soil moisture availability. One expects a fire would behave differently in live and dead fuels. But details of the combustion processes unique to living vegetation are unknown and may explain the dynamic fire behavior observed in these fuels. Fire spreads successfully in live chaparral fuels at higher fuel moistures than most of the experimental data used to develop the Rothermel model. Under the influence of strong Santa Ana winds, nearly 304,000 ha were burned in southern California during October 21–November 4, 2003 [24]. Fuel moisture content in live chaparral was around 60–85% at that time.

Given that current operational models do not adequately model fire spread in chaparral fuels and that data describing burning characteristics of chaparral fuels are limited, we have embarked upon an experimental effort to determine burning characteristics of live and dead chaparral fuels. In this paper, we focus on a simplified configuration of a fire plume. The fire plume represents a front of a propagating fire and includes all the relevant physical and chemical mechanisms occurring within a spreading flame front. It is basically a buoyant diffusion flame established over a finite mass of fuel in a container and characterized by three distinct regimes: the persistent flame, the intermittent flame, and the buoyant