IAWF
4th Fire Behavior
and Fuels Conference
Raleigh, NC
Feb 18-21, 2013

Fuel Element Combustion Properties for Live Wildland Utah Shrubs

Chen Shen, Thomas H. Fletcher
Chemical Engineering Department, Brigham Young University, Provo, Utah

Objectives

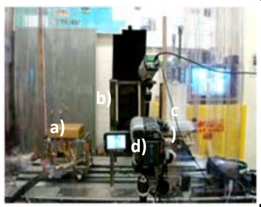
- Investigating the combustion behavior of four live Utah shrubs (Gambel oak (*Quercus gambelii*); canyon maple (*Acer grandidentatum*); big sagebrush (*Artemisia tridentata*); and Utah juniper (*Juniperus osteosperma*).)
- Developing an advanced bush-scale combustion model of these shrubs

Background

- Most wildland fire propagation models were developed based on experimental data from dead or dry fuel beds, which might be inappropriate for predicting live wildland fuel combustion, especially at high moisture content (Fletcher et al., 2007; Pickett, 2008).
- At Brigham Young University (BYU), more than 2200 experiments on single live fuel samples (various species common in California and Utah) have been conducted (Engstrom et al., 2004; Smith, 2005; Fletcher et al., 2007; Pickett, 2008).
- Pickett (2008) developed a first-generation two-dimensional model of Manzanita shrub combustion, based on empirical correlations developed from single leaf experiments. This bush model was capable of predicting overall burn times and amount of fuel unburned. This model was later extended to three dimensions (Prince et al., 2010), including effects of flame coalescence and the effects of wind on flame angle and size (based on the findings of (Cole et al., 2011)).

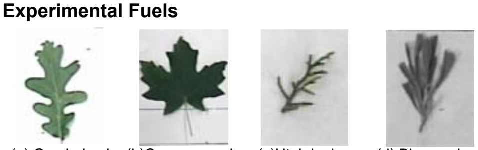
Experimental Setup

- A flat flame burner (FFB) was used as the heat source, which can be moved directly under the leaf.
- Fuel gases (CH_4 and H_2) and oxidizer (air) were premixed and introduced into the FFB, providing a 1 mm thick flame at a height of 1 mm above the sintered bronze burner surface (7.5" x 10").
- The vertical distance between the FFB and the leaves was typically 5 cm, a point where the gas temperature was 1200 K.



a) large flat flame burner, b) cage with glass panel on each side, c)mass balance, d) video camera.

Experimental Fuels



(a) Gambel oak (b)Canyon maple (c)Utah juniper (d) Big sagebrush

- Samples of Gambel oak, canyon maple and big sagebrush were collected from Rock Canyon at Provo, Utah.
- Utah juniper was from Diamond Fork Canyon near Spanish Fork, Utah.

Experimental Measurements

- Leaf geometrical parameters: individual leaf total mass (m_0), thickness (Δx), leaf width (W), leaf length (L), and moisture content (MC).
- Time-stamped images of combustion behavior along with time-dependent mass data via LabVIEW system.
- Combustion characteristics (time to ignition (t_{ig}), time of flame duration (t_{fd}), time to maximum flame height (t_{fh}), time to burnout (t_{brn}), and maximum flame height ($h_{f,max}$)) determined by an automated MATLAB routine modified for operating Utah species images of experimental runs.

Results

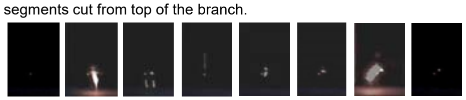
Qualitative Results

- Brand formation and bending behavior were observed for Gambel oak and canyon maple sample combustion. An example of horizontally placed Gambel oak sample combustion was shown in the following

3.266s 4.032s 5.954s 6.985s 9.063s 12.938s 16.266s 16.438s

Bending behavior and brand formation of Gambel oak sample placed horizontally. Numbers indicate the time stamp from the initial time of the experimental run

- Sparks accompanied with leaf material bursting out were observed for Utah juniper sample combustion mostly before ignition, especially for segments cut from top of the branch.



1.578s 1.641s 1.688s 1.750s 4.969s 5.016s 5.078s 5.141s

Spark and bursting behavior of Utah juniper sample. Numbers indicate the time stamp from the initial time of the experimental run.

- The first four and last four frames were consecutive frames.
- Sparks appeared on 1.641s and 5.078s, which disappeared suddenly in next frame.

Quantitative Results

Leaf geometrical properties

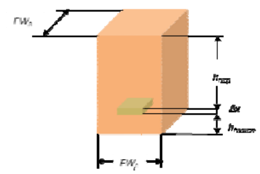
- Beta distribution: individual leaf dry mass (m_{dry})
- Multiple linear stepwise regressions with minimized Bayesian information criterion (BIC): Δx, W, and L (in this order).
  e.g. Gambel oak: Δx=0.27+0.052·MC+0.035·Ln(m_{dry})
  W=3.51-7.68·Δx+11.96·m_{dry}+3.76·m_{H2O}
  L=10.16+0.26·W+1.56·Ln(m_{dry})+0.50·Ln(m_{H2O})

Combustion characteristics

- Multiple linear stepwise regressions with minimized BIC: t_{ig}, t_{fh}, t_{fd}, $h_{f,max}$, t_{fh}, etc.
- Possible independent variables: W, L, Δx, m_0, m_{dry}, moisture mass (m_{H2O}), MC, etc.
  e.g. Gambel oak: t_{ig}=-1.15+1.59·MC-0.094·W+7.13·Δx
  t_{fd}=3.05+1.02·Ln(MC)+22.82·m_{dry}
  $h_{f,max}$=2.24-9.15·MC+2.04·W+1.54·L+24.55·Δx
  t_{fh}= 3.02-0.31·L+14.28·m_{H2O}

Modeling Results

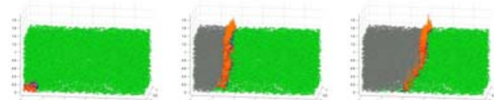
- A linear correlation between flame area (determined by images) and flame height was observed.
- The slope was defined as flame width (FW_β), which was integrated into the modified simulations of individual leaf flame volume.
- Stepwise regressions with minimized BIC were performed on FW_β:
  FW_β= 1.42+0.14·L+5.30·m_{dry}-3.70·m_{H2O}



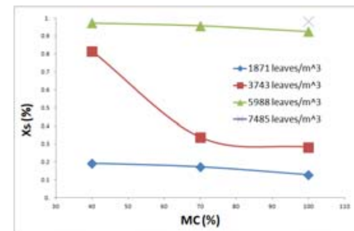
- Leaves are randomly placed into a defined 3-D space.
- The shape of this space (i.e. bush shape) is specific to species.

(a) Rectangular box canyon maple (b) Rectangular box Gambel oak (c) Hemi-ellipsoid Gambel oak

- The best prediction equations for leaf properties and combustion characteristics were embedded into the semi-empirical bush model.
- One of the experimental runs in the semi-empirical bush model is shown as the following figures.



- Percentage of burned versus moisture content at different levels of local density for large-hollow-space rectangular box Gambel oak bush.
- Both density and MC affected Xs significantly in the bush model. Different species also resulted in a different range of Xs.



- Different parametric runs were performed to study the effects of bush size, fuel placement shape, different leaf properties, fuel density, and wind.

Conclusions

In the semi-empirical bush model:

- Both density and species properties affected burning time and maximum flame height above the bush.
- Decreased MC and increased bulk density caused the extent of burnout (Xs) for the bush to increase.
- When wind was introduced and wind speed increased, Xs did not necessarily increase though the distance that the flame propagated from the ignition source increased.
- For simulated bushes matching geometrical measurements in the field, flame propagation and Xs were not as intense as expected, especially for the semi-ellipsoid Gambel oak bush and rectangular box maple bush.

References

Fletcher, T. H., B. M. Pickett, S. G. Smith, G. S. Spittle, M. M. Woodhouse, E. Haake and D. R. Weise, "Effects of Moisture on Ignition Behavior of Moist California Chaparral and Utah Leaves," Combustion Science and Technology, 179, 1183-120a3 (2007).
Pickett, B. M., "Effects of Moisture on Combustion of Live Wildland Forest Fuels," Ph.D., Chemical Engineering, Brigham Young University (2008).
Engstrom, J. D., J. K. Butler, S. G. Smith, L. L. Baxter, T. H. Fletcher and D. R. Weise, "Ignition Behavior of Live California Chaparral Leaves," Combustion Science and Technology, 176, 1577-1591 (2004).
Smith, S. G., "Effects of Moisture on Combustion Characteristics of Live California Chaparral and Utah Foliage," M.S., Chemical Engineering, Brigham Young University (2005).
Prince, D., B. Andersen, W. Cole, M. Dennis and T. H. Fletcher, "Modeling a Burning Shrub with and without Wind Using a Semi-Empirical Model," International Association of Wildland Fire 3rd Fire Behavior and Fuels Conference, Spokane, Washington, Brigham Young University (2010).
Cole, W. J., M. K. H. Dennis, T. H. Fletcher and D. R. Weise, "The Effects of Wind on the Flame Characteristics of Individual Leaves," International Journal of Wildland Fire, 20(5), 657-667 (2011).