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Short contribution – Fire Management

Effect of moisture content and ventilation on the burning rate of porous fuel beds

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1. Introduction

The burning rate of wildland fuels is not well understood. In most operational wildland fire models, a very simplistic model of burning rate and residence time is used that does not include the effects of fuelbed geometry, particle size and arrangement, ventilation, or moisture content (Albini 1976, Anderson 1969). The variation in burning rate with moisture content is examined here, both in a quiescent environment and subjected to ventilation. The fuel beds considered are wood cribs. Cribs consist of evenly spaced sticks that are stacked in cross piles. Unlike more realistic wildland fuelbeds, the use of cribs allows for a highly repeatable fuelbed that can be arranged to produce vary different qualities. Cribs are used frequently in the fire protection engineering field, and previous work has shown that they can provide useful insights into how the parameters of the fuelbed can directly influence fire behavior (McAllister and Finney 2016). Porous fuelbeds such as cribs have long been understood to burn in two different regimes (Gross 1962). The burning rate of densely packed fuelbeds is limited by oxidizer availability, so an increase in the fuelbed porosity allows for more oxidizer inside of the fuelbed and results in an increased burning rate. The burning rate of loosely packed fuelbeds however is governed by the heat and mass transfer processes of the individual fuel elements, and so it remains constant with increases in porosity.

2. Methods

As shown in previous work (McAllister and Finney 2016), the crib design can have unexpected influence on the results, so a range of geometries and sizes was tested. Five different crib designs were considered here that range in porosity from the densely-packed regime to the loosely-packed regime (see Table 1). Two different stick thicknesses were used (1.27 and 0.64 cm). Each crib design was tested at three moisture content levels (approximately 1%, 3.25%, and 6.5%). The moisture content was attained by conditioning the cribs for several days in a conditioning chamber set to a temperature and relative humidity chosen to produce the desired moisture content (35°C and 3% RH, 18°C and 17% RH, and 18°C and 40% RH). Each crib design and moisture content combination was tested in both quiescent conditions and subject to ventilation. In order to produce ventilation evenly through the crib, it was placed under a 3.66 m chimney. The gap between the top of the crib and the bottom of the chimney was held constant at 3 cm for all tests. The reduced plume entrainment due to the chimney forces ambient airflow through the fuelbed underneath. As seen in Figure 1, all cribs are placed on 3" spacers to allow for unrestricted airflow up through the bottom of the crib. For the tests with ventilation, the cribs are first lit away from the chimney. Once ignition was established, they were then rolled underneath the chimney where the burning rate measurements began. Burning rate was measured through the use of three load cells under the platform that recorded the change in mass at 10 Hz. The slope of the curve fits through the data produces the burning rate. Sample raw mass and burning rate data is shown in Figure 2. The reported value of the burning rate was the maximum rate achieved. Three replicates of each test were conducted and the results were averaged. Thus a total of 90 tests were conducted.

Table 1 - Crib designs tested. Cribs with porosity under 0.05 cm are considered densely packed.

Crib design #	Stick thickness (b, cm)	Stick length (l, cm)	Number of sticks/layer (n, [ ])	Number of layers (N, [ ])	Heskestad porosity (φ, cm)
1	1.27	12.7	5	10	0.0215
2	1.27	25.4	4	21	0.1202
3	0.64	25.4	10	10	0.7246
4	0.64	25.4	14	15	0.0213
5	0.64	30.5	8	14	0.1210

Figure 1 - Crib design #3 under 3.66 m tall chimney.

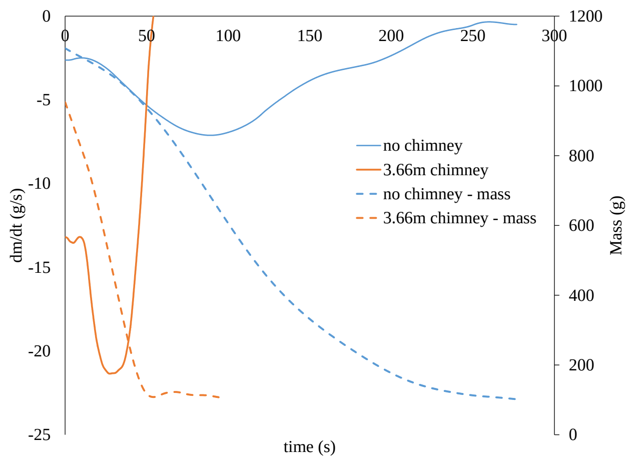

Figure 2 - Typical curves of mass loss rate (dm/dt) and mass as a function of time with and without ventilation provided by a 3.66m tall chimney.

3. Results and Discussion

Adding ventilation can have a dramatic effect on the burning rate. For example, the first two columns (light blue and orange) in Figure 3 show the average normalized burning rates of the five crib designs tested with 1% moisture content both with no ventilation (light blue) and the ventilation produced by the presence of a 3.66 m chimney (orange).

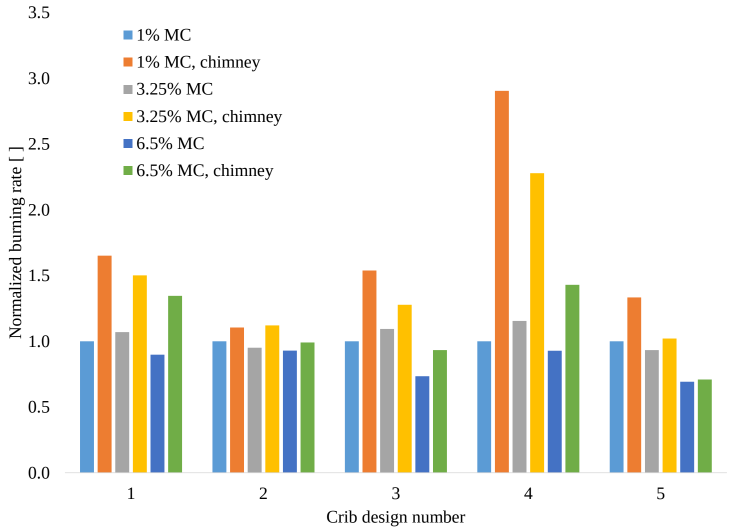

Figure 3 - Average normalized burning rate for each crib design at several MCs with and without ventilation due to the presence of a 3.66 m chimney. Burning rate normalized to 1% MC and no ventilation case.

All results were normalized compared to the 1% MC and no ventilation case. Depending on the crib design at 1% MC, the burning rate increased from 10.5% for crib design #2 up to 190.5% for crib design #4 compared to the non-ventilated cases. This increase in burning rate is caused by two mechanisms. For the densely packed cribs (designs #1 and 4), forcing air through the fuel bed essentially reduces the local equivalence ratio for these locally rich systems. Because the cribs are built with a charring material, this forced ventilation also increases the char oxidation rate. This could have important implications for wildland fires as it could promote flaming combustion over smoldering combustion, further increasing the fire intensity.

The moisture content had an interesting effect on the burning rate. As seen by comparing the light blue, grey, and dark blue columns in Figure 3, with no ventilation a small increase in moisture content (from 1% to 3.25%) may actually slightly increase the burning rate, such as for crib designs #1, 3, and 4. With ventilation, however, all crib designs either had the same or reduced burning rates for the same small change in moisture content (comparing the orange and yellow columns). All crib designs and ventilation conditions showed a decrease in burning rate as the moisture content increased further to 6.5%. However, the relative reduction in burning rate is more significant with ventilation. For example, crib design #4 had a 7.2% reduction in burning rate with no ventilation between 1% and 6.5% MC, whereas the decrease was 50.1% between in the cases with ventilation. Some of this may be a result of the method of ventilation and the fact that the ventilation is directly tied to the burning rate. Future work will include designing a testing apparatus that will blow a fixed flow through the bottom of the crib. Future work will also include testing crib designs with thinner sticks to examine the role of thermal thickness in this process.

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5. References

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