Characterization of live and dead pine needles during combustion

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1. Wildland Fuels

Understating the fundamental burning dynamics of forest fuels is a key element to the understanding of large scale wildfire development. It is know that differences in fuel flammability properties have an important effect on the wildfire intensity, flame height and spread rate. In Fire Engineering, fundamental understanding of fuel burning dynamics is studied best at the small scale using dedicated fire test apparatus like the Cone Calorimeter and the FPA. Given its importance, relatively little work is available in the literature on fundamental burning dynamics of forests fuels. This work studies compares the burning of two very common fuels, dead and live pine needles.

Figure 2. FM Global's Fire Propagation Apparatus (FPA). This calorimeter enables for different external heat fluxes and different flow condition to be applied on the samples.

Figure 3. Sample Holder with live needles. The Edinburgh porous sample holder used here and developed in [1]

2. Experiments *with* Fire Propagation Apparatus (FPA)

Calorimetry measurements were conducted using the FPA (**Figure 2**). The species used in this study is *Pinus halapensis* from South of France. This fuel is representative of the Mediterranean ecosystem and has been studied before [1]. Needles samples of 8 g were packed in a porous sampler holder (Figure 3) at a density of 20 kg/m^3, believed to be approximately representative of natural conditions in the forest. Live and dead needles were tested. The samples were subjected to an external heat fluxes (50 or 25kW/m^2) and flow through the bed (natural convection or forced flow). Three moisture conditions were tested; freshly collected needles in Spring time (measured water content 45 to 55% in wet base), needles at standard condition of 25 C and 50% air humidity and oven dried needles (zero water content).

Figure 1. Forest fire of a pine stand. Photo by John McColgan, BLM Alaska Fire Service.

3. Behaviour of Live *and* dead needles

The evolution of the heat released rate (HRR) and the mass loss rate (MLR) was measured for all 66 experiments. Discrete variables were also recorded including times to ignition, duration of the flame, time to burn out and peak HRR **Figure 4** and **Figure 5** compares the evolution of HRR and MLR in two tests, one dead and one live sample of needles

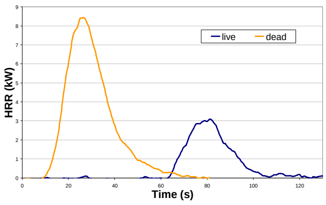


Figure 4. MLR comparison for live and dead pine needles with forced flow

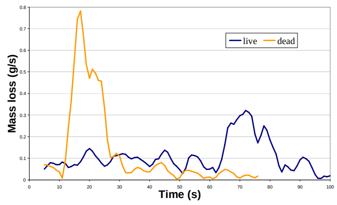


Figure 5. MLR comparison for live and dead pine needles with forced flow

	Time to ignition (observer) s	Burning time (s)	Time to peak HRR chemical from ignition (s)	Peak HRR/area chemical (kW/m2)	Max MLR (g/s)	Average post ignition MLR (g/s)	Average Heat of Combustion (kJ/g)
live							
no flow	57	36	15	210	0.35	0.13	9
	3	7	2	30	0.04	0.02	1
flow	60	38	18	199	0.34	0.16	8
	7	13	3	37	0.08	0.04	0
live dried							
no flow	13	24	20	319	0.70	0.20	19
	2	6	2	25	0.23	0.08	1
flow	17	14	14	391	0.89	0.48	18
	3	1	1	62	0.06	0.03	1
dead							
no flow	9	24	13	499	0.65	0.28	20
	1	2	2	29	0.05	0.03	1
flow	12	19	13	600	0.83	0.38	21
	2	5	1	49	0.11	0.08	2
dead dried							
no flow	14	12	18	448	0.94	0.51	23
	3	1	0	29	0.09	0.01	1
flow	9	21	22	338	0.71	0.30	21
	0	2	3	28	0.04	0.05	1

Table 1. Summary of all the 66 tests conducted. Averages (highlighted) and standard deviation (not highlighted). Each test was repeated four or five times.

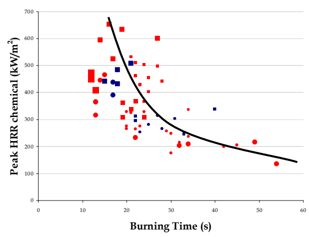
4. Results *and* analysis

Table 1 shows averages for particular tests. The data was analysed statistically to compare cases. The most significant difference was between live vs. dead and wet vs. dry samples. Moisture content had a small effect on dead needles but a large effect on live needles. Oven-dry live needles burn more like dead needles (8% moisture) than like fresh live needles (45% moist). HRR for the dry needles was between 140 to 200% greater than for live needles. Average mass loss rate for dry needles was between 115 to 140% greater. Average time to ignition were much faster for the dry needles (380 to 520% faster).

Legend (figures 6-11)
Red: 50 kW/m²
Blue: 25 kW/m²
■ (*square*): Dead needles
● (*circle*): Live needles
Big: Forced Flow
Small: Natural convection

Figure 6 Peak HRR vs burning time.

The 1/t trend indicates equal amounts of energy being produced (because equal mass content in samples)



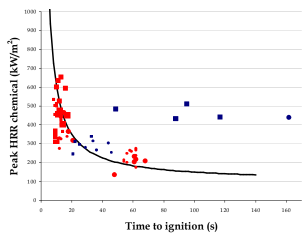
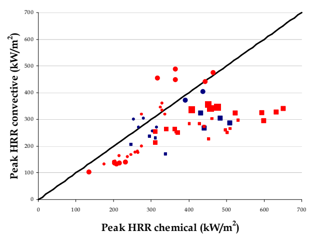


Figure 7 Peak HRR vs time to ignition.

The trend 1/t indicates slower ignition for lower peak HRR. Only two cases (live and dead, 25 kW/m² with flow) differed from the trend possibly due to the density and flow relation of the sample.

Figure 8 Peak HRR chemical vs Peak HRR convective

Comparison with the diagonal shows the divergence of dead needles in contrast to live towards a higher chemical HRR possibly due to a differences in gas composition



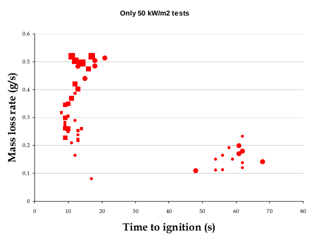
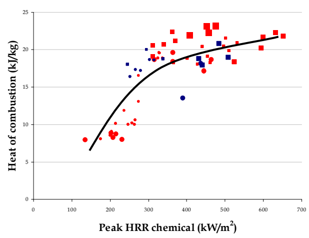


Figure 9 MLR vs Time to ignition.

It shows different behaviour between dead and live dried needles vs plain live needles. Live needles have longer time to ignition and lower MLR values in comparison to dead and live dried needles

Figure 10 Heat of combustion vs peak HRR chemical.

It shows different behaviour between dead and dry live needles vs. fresh live needles. Live needles have lower peak HRR and heat of combustion values in comparison to dead and live dried needles during burning.



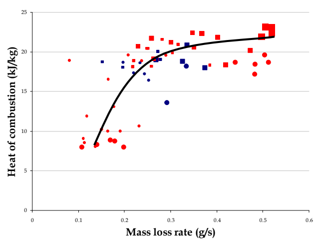


Figure 11 Heat of combustion vs MLR.

It shows a different behaviour between dead and live dried needles vs fresh live needles. Live needles have lower MLR and heat of combustion values in comparison to dead and live dried needles during burning.

5. Concluding Remarks

Overall there was good repeatability of data. The experiments showed the difference in burning dynamics of live and dead pine needles are significant and must be taken into account when explaining or prediction wildfire behaviour.

Dead needles will ignite and burn faster and with a higher intensity than live needles will. Flow in the porous bed increased HRR and mass loss rate for dead needles; but the reverse was observed for live needles. Moisture content was not an important factor for dead needles but very important for live. Once live needles were oven-dried, its behaviour resembles more that of dead needles than fresh live ones.

More experiments are needed to study the effect of different packing densities, sample size and pine species.

1. Schemel, Simeoni, Biteau, Rivera, Torero , A calorimetric study of wildland fuels, Experimental Thermal and Fluid Science 32 (7), pp 1381-1389, July 2008.