BURNOUT OF LARGE-SIZED WOODY FUELS

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ABSTRACT

The burnout of large-sized woody fuels, 1 to 6 inches thick, is being measured at the USDA Forest Service Northern Forest Fire Laboratory in Missoula, Mont. Physical properties of the fuel bed are varied to determine thresholds for interactive burning, periods of flaming and glowing combustion, and the accuracy of a mathematical model that describes combustion during the flaming phase of burnout. Critical fuel properties include loading, fuel size, and spacing--the distance between outside edges of pieces of the same size. This work is being related to the heat loads on the site and the fire effects on physical and biological features of urban and rural situations.

INTRODUCTION

Research on fire behavior in wildland fuels in the 1930's was directed toward rate of spread and resistance to control (1, 2). As work continued through the 40's, 50's, and 60's, additional knowledge was developed and fire danger rating systems were formulated (3, 4, 5). Ignition, rate of spread or area growth, and flame length were among the variables considered as the fire danger rating was developed. During the 1960's and 70's, work progressed on developing models of fire behavior and these were incorporated into the current National Fire Danger Rating System (6, 7).

The needs of the resource specialist, however, extend beyond expressions of fire danger to greater detail of fire behavior and effects; therefore additional aids are still being produced (8, 9, 10). This work has culminated in a set of mathematical models for estimating the forward rate of fire spread, the rate of perimeter and area growth, flame length, fire line and area fire intensity, fuel consumption rate, and burnout of fuels.

Because the basic fire behavior mathematical model only considers fuels less than 3 inches in diameter, another model, BURNOUT (9), was developed to estimate fire behavior after the initial fire front has passed. The random array of fuel sizes in a fuel bed are considered in terms of their individual burning times, the spacing of pieces of each size, and the planform projection overlap of fuel pieces of equal size and smaller. The amount of load loss and the rate of loss is summed for the fuel sizes by means of a universal burnout function and its derivative based on the burn time for the flaming phase of combustion. The model predicts the fuel consumption and provides a time history of the fire intensity in mixed fuels, including large fuels found in logging slash, wind-thrown timber, or debris from blast effects, earthquakes, and other catastrophies. The burnout model was developed using the weight loss data generated during the Flambeau series of burns. The model estimates fire behavior and fire effects, not only in wildland situations, but also for urban sites where blast and secondary ignitions can pose serious fire hazards (11).

PURPOSE OF CURRENT WORK

Although forest fire behavior research has generated several useful products for fire specialists, some uses have been hampered because current fire spread models do not consider fuels larger than 3 inches in diameter. Specialists know that large fuels are an important consideration in management plans, but they have had no means of quantification. The results of modeling heat release per unit area and burnout time have not been exercised enough to determine their applicability.

Ongoing research will provide methods for assessing the impact of the fire behavior of large-sized fuels on the site (fire effects) and aiding man's response to actual or expected fire behavior (fire and resource management). Four areas of effort are involved:

1. Testing the theoretical burnout model against experimental fires to confirm the model and define areas of deficiency.

2. Determining the fire behavior associated with the physical properties of large-sized fuels, explaining their role in fuel bed burning processes, and describing the heat flow to the surroundings.

3. Identifying the significant roles of large-sized fuels in fire behavior and coupling these functions to site and resource activities so fire effects can be assessed.

4. Identifying the fire behavior features of large-sized fuels associated with the fire front, the flaming combustion phase, and the glowing combustion phase.

PLANS AND PILOT TESTS

A series of burns has been started in our combustion laboratory. Fuels range from 1 inch (2.54 cm) to 6 inches (15.24 cm) and fuel area loadings from 3 to 40 lb/ft^2 (14.65 to 195.3 Kgs/m^2). The first series used fuel beds of excelsior, 1/4-inch (0.63 cm) sticks, and 1-inch (2.54 cm) square sticks on a load area of 2 square feet (0.186 m^2). The next four beds were constructed on load areas of 16 square feet (1.49 m^2). The largest sized fuel piece in each successive fire was 1-, 2-, 4-, or 6-inch (2.54, 5.08, 10.16, 15.24 cm) dimensioned lumber. The physical properties are presented in table 1.

Evaluation of the burnout model will involve determining the fractional weight loss rate of each size class to the overall weight loss rate observed during the history of the fire. In addition such things as the fuel spacing in each size class will be studied to confirm or modify the assumed threshold spacing for interaction that results in mutual burning. The flaming phase and the glowing phase of the combustion process will be measured so flame height computations based on mass loss rate can be adjusted for mass loss due to glowing combustion. Other observations relate the burnout to the radiant heat received at a point away from the fire and to the heat flow into the medium beneath the fuel bed.

Table 1.--The physical properties of the fuel beds burned in the first series. Spacing defines the fuel separation for a given size in terms of their thickness, t.

BURN NUMBER	Total fuel load	Depth	Excelsior fuel load	1/4-inch and spacing	1-inch and spacing	Large-size fuel		
						Thickness	Layers and spacing	Fuel load
	lbs/ft^2	ft	lbs/ft^2	lb/ft^2:xt	lb/ft^2:xt	in.	no.:xt	lb/ft^2
1T1-4	3.88	1.08	.11	1.02:5t	2.74:3t	--	---	---
1T1-5	3.47	1.08	.13	.80:5t	2.54:3t	--	---	---
2T11-1	10.79	1.08	.11	.98:5t	2.77:3t	2	3:1.5t	6.94
2T6-1	21.94	2.75	.15	2.43:5t	6.33:3t	4	3:2.7t	13.04
3T13-1	27.50	3.08	.14	1.00:8t	2.88:5t	6	3:1.5t	23.48

After this first series of fires is analyzed, we will develop a cycle of burns where spacing and loading by size class are altered to complete the investigation of the burnout model. We plan to investigate the effect of timber type upon burning and perhaps the effects of fuel moisture content. As we gain information on the fire behavior of large-sized fuels, field studies are planned utilizing prescribed burns to extend the research findings to operational situations. This phase will depend on the availability of manpower and operating budget. Approximately 1 year has gone into this study; another 3 years are needed.

RESULTS OF WORK TO DATE

The burnout model's fractional weight loss rate is based on a modified "top hat" burning rate history. During the first third and the last sixth of the weight loss for each fuel size, the burning rate is assumed to change linearly with time, while the center portion of the burnout curve has a nearly constant rate. The weight loss data were converted to a fractional loss rate and compared to the model predictions (fig. 1). Although predicted burning rates are in agreement, the flaming times are longer than those experienced in the laboratory. The flaming period usually runs 20 minutes or less, but the model predicts about 17, 35, 67, and 98 minutes for the 1-, 2-, 4-, and 6-inch (2.54, 5.08, 10.16, 15.24 cm) sticks, respectively. The glowing combustion phase, which is not considered in the burnout model, continues for a much longer period: more than 2 hours for the 1-, 2-, 4-inch (2.54, 5.08, 10.16 cm) sticks, over 5 1/2 hours for the 6-inch (15.24 cm) sticks, at an initial moisture content of 6 percent.

Energy release rates on the 16-ft^2 (1.49 m^2) beds during the flaming period of the finer fuels ranged from (229 to 522 Btu/ft^2-s (621 to 1416 Kcal/m^2-s). After burnout of the 1/4-inch sticks, the fractional weight loss rates show no consistent burnout rates for the large-sized fuels, but generally exhibit a decreasing rate, with abrupt shifts as fuels are rearranged when the bed structure begins collapsing. The fractional weight loss rate ranges from 0.1 and 0.01 $min.^{-1}$ during flaming and from 0.01 and 0.001 $min.^{-1}$ during the glowing phase.

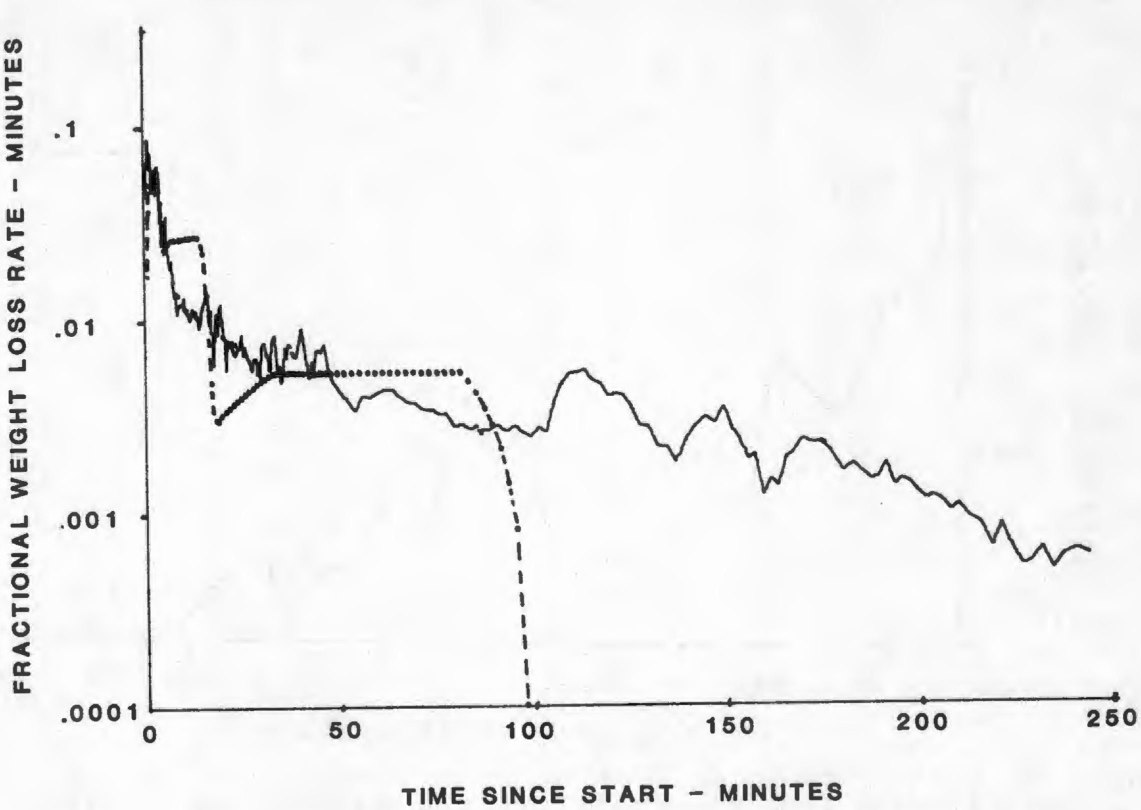

Figure 1.--Fractional weight loss rates are determined from strain-gage weight-loss measurements and compared to mathematical model output (dashed line) for a burnout theory.

Thermal gradients into a sand substrate beneath the fuel bed are measured with two arrays of thermocouples arranged vertically at 1-cm spacings. This information will be related to physical and biological functions that indicate the fire's effect on the site. The maximum temperature gradient in the first centimeter of sand averages about 1,567°F/in (325°C/cm); the peak occurs during the flaming phase. The maximum sand surface temperature experienced was 1,420°F (771°C) occurring more than 1 1/2 hours after the fire start. The total time for heat flowing into the sand has ranged from 55 to over 200 minutes. The heat flux into the sand did not exceed 2.92×10^3 Btu/ft^2-hr (0.22 cal/cm^2-s) (fig. 2).

The flames generated from a bed of woody debris are part of the hot gas plume that can carry embers and that contribute to the radiant heat load adjacent to the burning area. Therefore flame heights are measured visually and photographically. These data have been compared with a model of flame height used in estimating firebrand lofting (12). The model uses the weight loss rate to predict flame height. This allows us to estimate when glowing combustion becomes a significant part of the weight loss and also allows us to check the flame height model's accuracy. Peak flame heights occur within the first 2 minutes of the fire and are underestimated by the model; however, the flame heights associated with the 1-inch burnout are accurately predicted. Flame height is overestimated for the burnout of the larger fuels because of the glowing combustion contribution to weight loss. In addition we are correlating the radiant heat to the flame height and weight loss data to develop interpretative guides for the radiation environment.

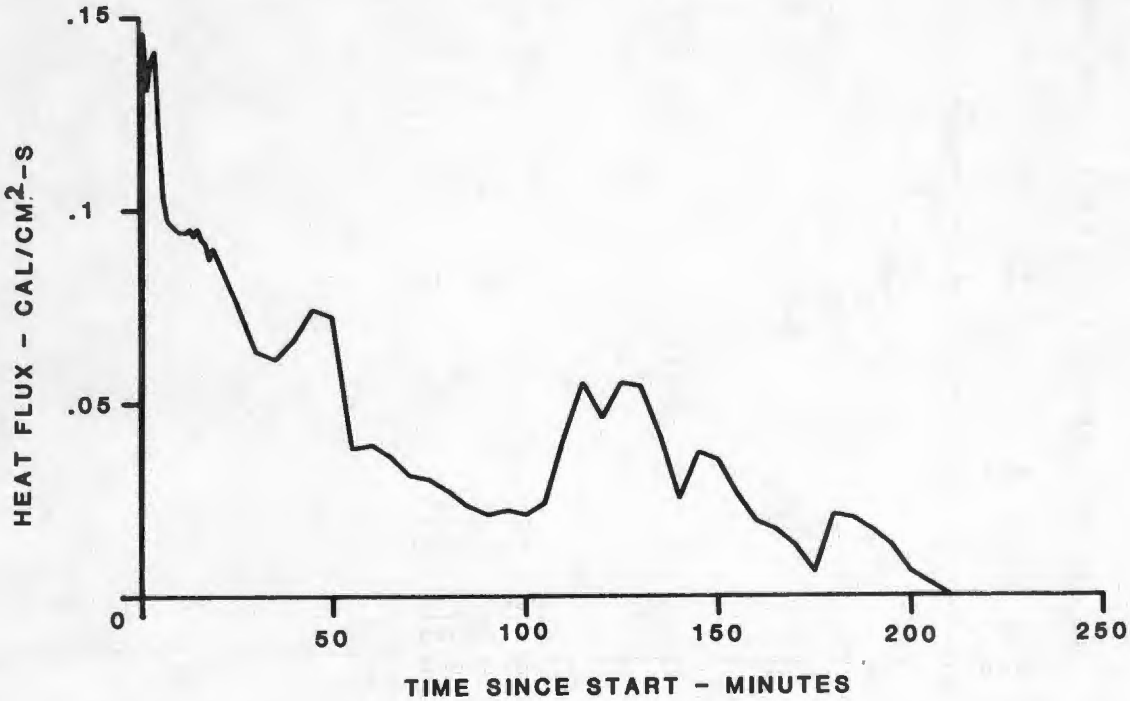

Figure 2.--Heat flow into the surface of a dry sand layer determined by an array of thermocouples. Thermal conductivity of dry sand was determined to be 0.487 mcal/cm-s-°C

SIGNIFICANCE OF RESULTS

These initial burns suggest the spacing of large-sized fuels must be closer than assumed in the burnout model in order to have mutual and interactive burning. Fuels of a given size probably have to be within 1.5 diameters of each other for interactive burning, but the critical spacing is at least a function of fuel size and the number of vertical layers involved. It is doubtful that two layers of fuel elements of the same size would interact to maintain flaming combustion while three or four layers probably would interact at spacings 1.5 diameters or less.

The glowing combustion phase is an important aspect of the burnout of a fuel bed. Glowing starts exerting its influence early in the fire history and continues 10 to 20 times longer than the flaming phase. Glowing will have a major effect upon the site, being lethal to soil organisms and causing physical changes in soil properties.

The experimental burns and associated field studies will provide numerical checkpoints for establishing bounds of energy release rates and flame heights that can be experienced. Consideration of the glowing combustion phase, the heat flow conducted below the fire, and heat radiated or convected away from the fire will be useful in restricting access to the area, establishing shelter needs, and estimating the potential for fire-induced winds.

Results from experimental fires such as have been described provide data for describing the burning regimes and intensities expected during the growth and decay of fires in rural and urban situations.

REFERENCES

1. J. R. Curry and W. L. Fons, "Rate of Spread of Surface Fires in the Ponderosa Pine Type of California," Journal of Agriculture Research 57:4, (1938).

2. L. G. Hornby, "Fuel Type Mapping in Region One," Journal of Forestry 33(1), 67-70 (1935).

3. H. W. Beal, Forest Fire Danger Tables, Department of Mines and Resources, Ottawa, Canada (1946).

4. U. S. Department of Agriculture, Forest Service, The Wildland Fire Danger Rating System (1968 ed.), 108 p., Pacific Southwest Forest and Range Experiment Station, Berkeley, California (1958).

5. A. G. McArthur, Fire Behavior in Eucalypt Forests, Leaflet No. 107, 36 p., Forest Research Institute, Canberra, Australia (1967).

6. R. C. Rothermel, A Mathematical Model for Predicting Fire Spread in Wildland Fuels, USDA Forest Service Research Paper INT-115, 40 p. Intermountain Forest and Range Experiment Station, Ogden, Utah (1972).

7. John E. Deeming, James W. Lancaster, Michael A. Fosberg, and others. The National Fire-Danger Rating System, USDA Forest Service Research Paper RM-84, 53 p. (rev.), Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado (1974).

8. Frank A. Albini, Estimating Wildfire Behavior and Effects, USDA Forest Service General Technical Report INT-30, 92 p, 74 ref., Intermountain Forest and Range Experiment Station, Ogden, Utah 84401 (1976).

9. F. A. Albini, Computer-based Models of Wildland Fire Behavior: a users' manual, 68 p., USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah (1976).

10. Andrews, Patricia L., A System for Predicting the Behavior of Forest and Range Fires, In: Proceedings 1983 SCS Conference on Computer Simulation in Emergency Planning, January 27-29, San Diego, California (1983).

11. T. A. Reitter, D. B. McCallen, and S. W. Kang, Literature Survey of Blast and Fire Effects of Nuclear Weapons on Urban Areas. Final report, June 1982, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California 94550 (1982).

12. F. A. Albini, Spot Fire Distance from Burning Trees--a Predictive Model, USDA Forest Service General Technical Report INT_56, 73 p., Intermountain Forest and Range Experiment Station, Ogden, Utah (1979).