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Energy Release Rates in Fire Retardant Evaluation

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Rate of spread and other indirect measurements of fire intensity are often used as measures of flammability when fire-retardant chemicals are evaluated under laboratory conditions. The authors describe a system for obtaining the energy release rate directly and show its importance and relation to retardant effectiveness.

FIRE researchers working to develop more effective chemical fire retardants long have looked for a convenient way to compare effects of various fire-retardant chemicals on flammability. Flammability has been defined as the interaction of ignitibility, sustainability, and combustibility.[1] Ignitibility is the ease with which a fuel will ignite. Under given conditions, the most ignitible fuel will ignite spontaneously with the least energy input. A measure of the ability of a fuel to continue to react exothermally following ignition quantifies the sustainability of the fuel. Combustibility of a specific fuel is the rapidity with which energy is released from the fuel following ignition. Fire retardants are used primarily to reduce both the combustion rate and the ability of the fire to propagate itself. Consequently, it is necessary to quantify these parameters in any chemical evaluation of retardants. The ability of the fire to propagate itself can be evaluated by the rate of spread, which can be measured easily either by visual or more sophisticated means. Quantification of the combustion rate, or fire intensity, is more difficult but can be accomplished by several methods.

ENERGY RELEASE RATE

In studies by Phillips and Miller,[2] Dibble *et al.*,[3] Johansen,[4] Hardy *et al.*,[5] and Muraro,[6] such parameters as radiant energy flux, convection column temperature, and flame height were measured in attempts to quantify and compare a chemical's effect on fire intensity. Rothermel and

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Hardy,[7] working with a weighing system described by Breuer,[8] used rate of weight loss in addition to rate of spread and radiant heat flux to determine the influence of moisture on the effectiveness of fire retardants. In a study of fire spread characteristics, Rothermel and Anderson[9] developed a method based on the mass loss rate per unit area to evaluate fire intensity. The potential energy of a particular fuel is the product of the mass of organic matter and the heat content of that fuel. The change in mass thus was shown to be proportional to the energy released by the fire. The energy release rate per unit area is defined as the equivalent unit energy release rate (E_R) and is obtained by dividing the combustion rate by the combustion area.

$$E_R = \frac{(weight\ loss\ rate)\ (energy\ equivalent\ of\ fuel)}{(combustion\ area)}\ Btu/ft^2-min$$

The heat content of unburned fuel in the convection column is assumed to be negligible.

Delineation of the primary combustion area is impractical when measuring the weight loss of chemically treated fuel beds because of the reduction and irregularity of the flame front and the forward rate of spread. In addition, some chemical retardants promote glowing combustion at the expense of flaming combustion. Difficulty in defining the combustion area at any particular time necessitates an evaluation on a simple energy rate basis. Thus, in order to compare the effects of chemicals on test fires, we have designated the energy release rate from the fire as E expressed in Btu/min. This energy release rate could be divided by the width of the fuel bed to provide an energy release rate per unit of flame front as outlined by Byram.[10]

The energy release rate is a function of both flaming and glowing combustion. A chemical that alters flaming combustion may or may not affect glowing combustion and, therefore, might produce different energy release rates. Recent studies performed at the Northern Forest Fire Laboratory[11] have shown that, while chemicals can have a similar reducing effect on the rate of spread, they do not necessarily reduce the energy release rate to the same extent. It is desirable for a fire-retardant chemical to reduce both the rate of spread and the energy release rate since the two are interrelated. Moreover, the latter often affects the ease with which control is attained. Any condition that is apt to occur during an intense fire (e.g., spotting) should be considered when weighing the importance of energy release rate measurements. In other cases, it may be desirable to reduce the rate of spread, but to maintain a high energy release rate to effect greater fuel consumption (e.g., prescribed burning).

SYSTEM FOR OBTAINING ENERGY RELEASE RATE

In order to determine the interaction between E, rate of spread, residue, and other variables, we adopted a simple and dependable system for continuous measurement of weight. The method of evaluating chemicals is similar to that used by Rothermel and Hardy;[7] burning characteristics of treated fuel beds 8 ft long, 18 in. wide, and 3 in. deep were compared. The preparation of these reproducible fuel beds was described by Schuette.[12] Fuel bed configuration requires a multiple point weighing system that is capable of monitoring a weight loss of 6 lbs or less, depending on the fuel type and loading. An untreated 3-ft-long starter bed is used in conjunction with the 8-ft treated bed. Fuel loadings are similar. Weight loss from the treated segment only is recorded.

Weighing systems utilizing transducer-type elements and load cells, such as one manufactured by the Statham Instrument Company,[13] offer several advantages in multiple measurement applications. These transducers convert an input quantity into a proportional electrical output that can be recorded continuously. The electrical output of multiple transducers can be summed easily and averaged to provide a single direct measurable output. One such transducer, an unbonded strain gage, consists of conducting filaments that have a resistance influence by force or displacement. The sensitivity of these filaments makes possible the adaptation of various load cells to the transducing cell.

The multiple strain gage transducer-type weighing system and the positioning of starter and treated fuel beds are shown in Figure 1. To minimize temperature effects, certain precautions were taken to prevent both conductive and radiant heating of the load cell. This system shows negligible temperature effects caused by the fire under test conditions. A schematic of the signal summation and averaging circuit used to integrate outputs from the four individual transducers is shown in Figure 2. The system as shown is equipped with four 20-lb load cells. While monitoring a fuel load of 6 lbs, it has a sensitivity of about ± 0.25 per cent or ± 0.001 lb.

ENERGY RELEASE RATE OF TEST FIRES

Data pertaining to several test fires were selected in order to demonstrate how this weighing system provides information relating to the energy release rate, E, and its importance to comparisons of the effects of fire-retardant chemicals (Figure 3).

Data pertaining to the treatments and to their effects on certain fire characteristics are summarized in Table 1. Figure 4 shows the effects of ammonium sulfate, $(NH_4)_2SO_4$, and of diammonium phosphate, $(NH_4)_2HPO_4$, on the weight loss of a ponderosa pine needle fuel bed. All tests were conducted in a wind tunnel under controlled environmental conditions — temperature, 90° F; relative humidity, 20 per cent; and wind, 5 mph. Under these conditions, only slight differences due to treatment can be noted in the initial energy release rate. A derivative circuit was used to

NOTE: Mention of trade names does not necessarily imply endorsement by the USDA Forest Service.

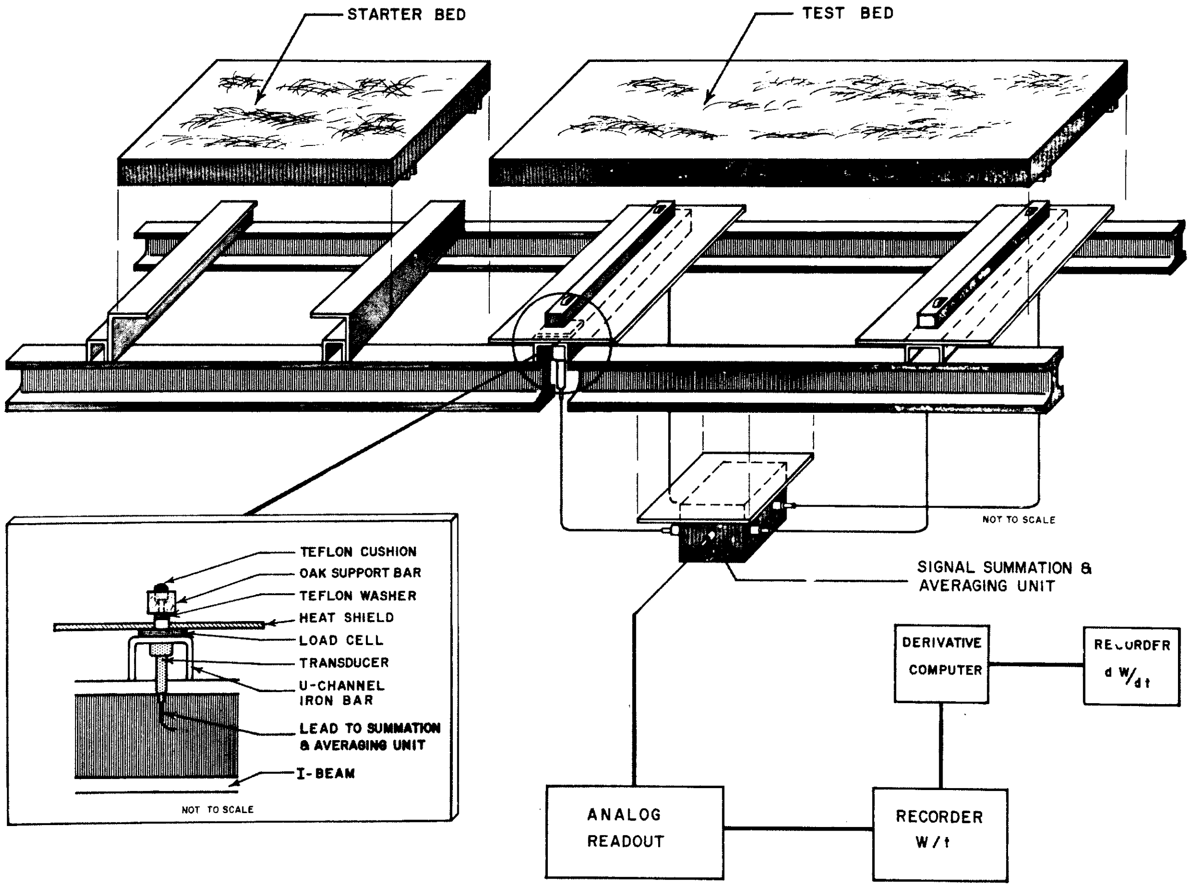

Figure 1. Multiple strain gage transducer-type weighing system and the positioning of the starter and treated fuel beds.

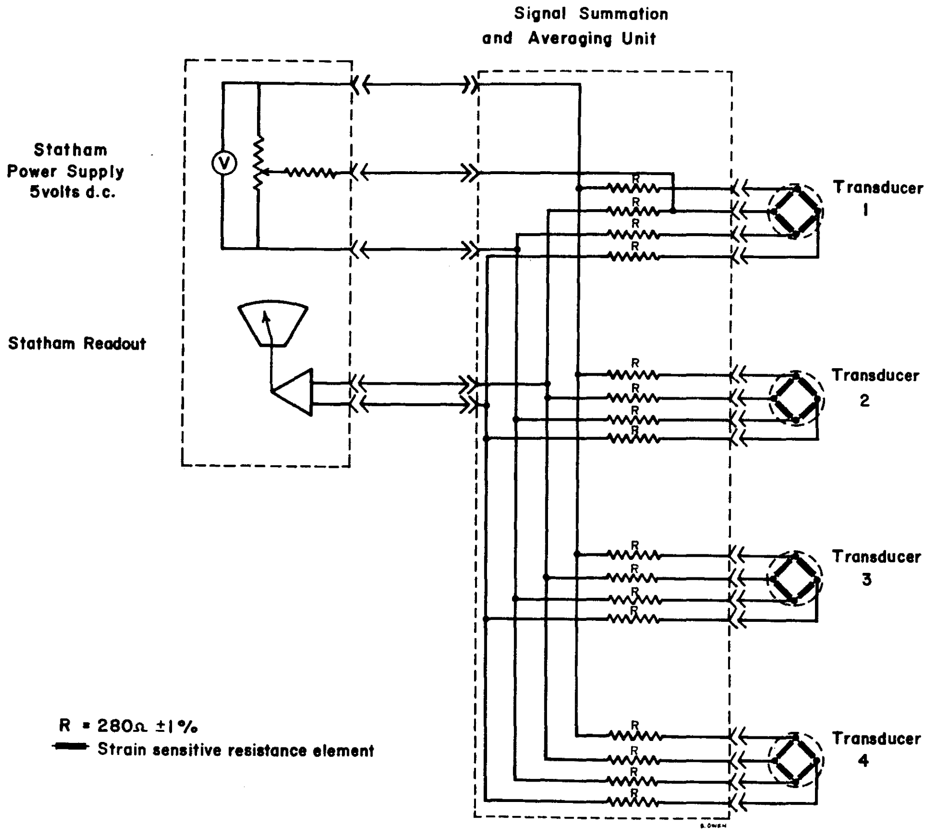

Figure 2. Schematic of the signal summation and averaging circuit used to integrate outputs from the four individual transducers.

provide added data on the rate of weight loss as a function of time. Because of its extreme sensitivity to rate changes, the derivative circuit magnified apparent differences in energy release rates and provided more definitive data. The derivatives of the weight loss curves (dw/dt or the rate of weight loss) are shown in Figure 5. A comparison of rate of weight loss curves for treated and untreated fuel makes it apparent that retardant chemicals reduced the maximum rate of weight loss, or energy release rate, while increasing its duration.

When the curves showing the rates of weight loss for fuel beds treated with diammonium phosphate are compared with those for beds treated with ammonium sulfate, it is evident that ammonium sulfate prolongs the duration of a relatively high energy release. Even so, the intensity is lower than that of the untreated fuel bed. Moreover, the fuel bed treated with ammonium sulfate released 12 per cent more total heat than the fuel bed treated with diammonium phosphate. The difference in energy release rates for the two treatments, as well as total heat released, may represent a difference in the extent of glowing combustion.

Figure 3. Fuel bed positioned and test fire in progress.

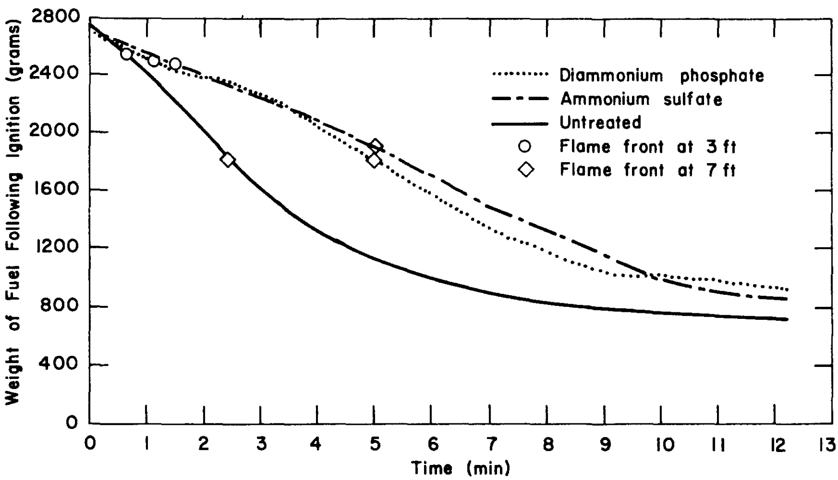

Figure 4. Effects of ammonium sulfate and diammonium phosphate on the weight loss of a ponderosa pine needle fuel bed.

Although the three test fires were not replicated and evaluated statistically, it is evident that these retardants have similar effects on the rate of spread reduction, while their effects on the rate of energy release and fuel consumption are distinctly different. Statistical differences do exist for the effects of diammonium phosphate and ammonium sulfate on the rate of spread, rate of weight loss, and residue.[14]

CONCLUSIONS

Multiple point weighing systems can be used to adequately monitor small weight changes as test fires burn. A derivative circuit can be used to

TABLE 1. *Burning Characteristics of Treated and Untreated Fuel Beds*

Fuel bed data	*Untreated*	*10 per cent* $(NH_4)_2HPO_4$	*10 per cent* $(NH_4)_2SO_4$
Ponderosa pine needles (7 per cent moisture content), *lbs/ft*^{2}	0.50	0.50	0.50
Dry chemical, *lbs/ft*^{2}	0	0.018	0.019
Chemical (dry fuel basis), %	0	3.6	3.8
Average rate of spread measured during steady state (3–7 ft), *fpm*	2.3	1.0	1.1
Average rate of weight loss measured during steady state (3–7 ft), *lbs/min*	0.86	0.39	0.35
Average energy release rate measured during steady state (3–7 ft), *Btu*	7.5×10^2	3.4×10^2	3.1×10^2
Maximum rate of weight loss, *lbs/min*	1.06	0.72	0.59
Maximum energy release rate, *Btu/min*	9.3×10^2	6.3×10^2	5.2×10^2
Residue after completion of flaming and glowing combustion, *lbs*	0.66	1.39	0.87
Original weight remaining (dry fuel basis), %	11.8	24.8	15.5
Total heat released during flaming and glowing combustion, *Btu*	4.3×10^4	3.7×10^4	4.1×10^4

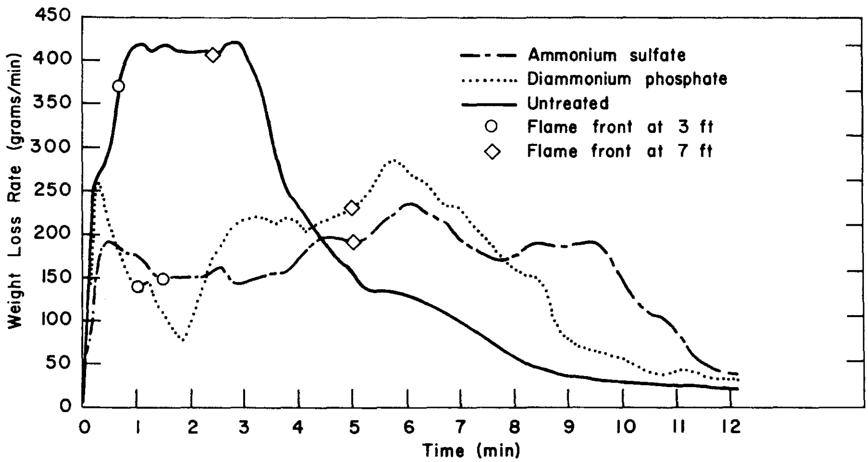

Figure 5. Effects of ammonium sulfate and diammonium phosphate on the rate of weight loss of a ponderosa pine needle fuel bed.

augment information pertaining to the rate of weight loss or to the combustion rate.

Chemicals that have similar effects on the rate of spread, and consequently on flammability, *can* have different effects on the rate of energy release.

Energy release rates can be important to evaluations of the effects of fire-retardant chemicals.

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