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# A MOBILE HEAT APPLICATOR FOR SIMULATING PRESCRIBED FIRE INTENSITIES

Abstract. --In testing the degree of tolerance or susceptibility of tree stems to heat from prescribed fires, it is desirable to apply controlled quantities of heat to the lower bole. This paper describes an infrared heater capable of simulating the intensities of prescribed fires and mobile enough for use in the field under natural conditions. Procedures for calibrating the unit are discussed.

## INTRODUCTION

Prescribed fire is used as a silvicultural tool in controlling undesirable hardwoods in even-aged management of southern pine stands throughout the Coastal Plain and Piedmont. Heretofore, fire prescriptions for the control of undesirable species have been based primarily on experience and empirical data. As prescribed burning becomes more of a science, and as more precise prescriptions are required, a strong need arises for factual data on the effects of fire on trees. Pre-eminent is the need for reliable data on cambial response to specific intensities of heat applied to the outside of the bark for known exposure times--such as would occur in a prescribed fire. From such data, time- temperature combinations lethal to the cambium could be determined, and these could serve to define heat-intensity limits of prescribed fires for selective control of undesirable species.

In implementing a study to determine these combinations of fire intensity and length of application for hardwood stems in southern pine forests, we found it necessary to develop a mobile unit for applying specific quantities of heat to selected tree stems under field conditions. Previous researchers have used various means of applying such heat, depending on their specific study objectives. Hare[1] used a standardized propane flame for applying heat to small areas of the boles of different species of trees to determine their relative resistance to heat. Kayll[2] used a larger propane torch for applying different amounts of heat to small areas on eastern white pines. In his work on heat transfer through bark,

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[1] Hare, Robert C. Contribution of bark to fire resistance of southern trees. J. For. 63: 248-251. 1965.

[2] Kayll, A. J. A technique for studying the fire tolerance of living tree trunks. Can. Dep. For., Dep. For. Publ. 1012, 22 pp. 1966.

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Vines[3] used a single, propane-fueled, radiant panel similar to those we will describe, Apparently he did not alter the intensity of heat application. Gill and Ashton[4] used an electric radiant heater mounted in hinged reflector heads that could be positioned around a portion of the circumference of a tree trunk. Other techniques have included hot air blowers and Hare's' use of oil-soaked wicks wrapped around the trunks of trees.

The heat source in our case had to be capable of producing intensities of heat similar to prescribed fires burning in common fuels of southern forests. Careful consideration was given to selecting the equipment so that the same amount of heat could be applied to each square inch of surface area for stems 2, 3, and 4 inches in diameter. The width or length of stem treated had to be adequate to minimize longitudinal transfer of heat away from the treated area. This paper describes the design and test procedures used in developing a suitable piece of equipment.

## DESIGN

The mobile heat applicator consists of four infrared heaters' mounted on a framework which rides on 20-inch bicycle wheels (figures 1 and 2). The heaters are fed through high-pressure rubber hose from a tank of liquefied petroleum gas (LPG) via a dispersion manifold. The manifold is equipped with quick-connect couplings between the heater heads and a storage tank to facilitate dismantling and add flexibility to the unit. All heaters are adjustable horizontally in two directions, as well as vertically, to accommodate placement at each test tree. The heaters are set to be used 24 inches above ground, but vertical height can be adjusted up to 36 inches with the use of the three stabilizing rods. These rods, in conjunction with bubble levels attached to the slide frame for the heaters, are also used to level the unit. Four heater heads are generally used during heat application, but three burner heads can be used when it is necessary to have the heater faces closer to stems with very small diameters. The front slide frame is detachable to allow the unit to encircle the tree (fig. 2). Although the design and weight of the unit make it appear awkward, it is relatively easy to propel through the woods because of the large tires. A large, swivel-caster wheel can be attached to the front stabilizing rod to help support the heater slide frame.

## CALIBRATION AND TEST PROCEDURES

In calibrating the unit, we used cylindrical, water-filled, heat-sink calorimeters 2, 3, and 4 inches in diameter so that they would correspond with the sizes of tree stems treated during the study. Two types of calorimeters were used: Type I consisted of three calorimeters made from

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[3] Vines, R. G. Heat transfer through bark, and the resistance of trees to fire. Aust. J. Bot. 16: 499-514. 1968.

‘Gill, A. M., and Ashton, D. H. The role of bark type in relative tolerance to fire of three central Victorian eucalypts. Aust. J. Bot. 16: 491-498. 1968.

‘Hare, Robert C. Bark surface and cambium temperatures in simulated forest fires. J. For. 63: 437-440. 1965.

‘Heater heads are 5- by 8-inch Perfection Schwank Gas Infrared Heaters manufactured by Hupp Corporation. Mention of commercial products does not constitute endorsement by the U. S. Department of Agriculture.

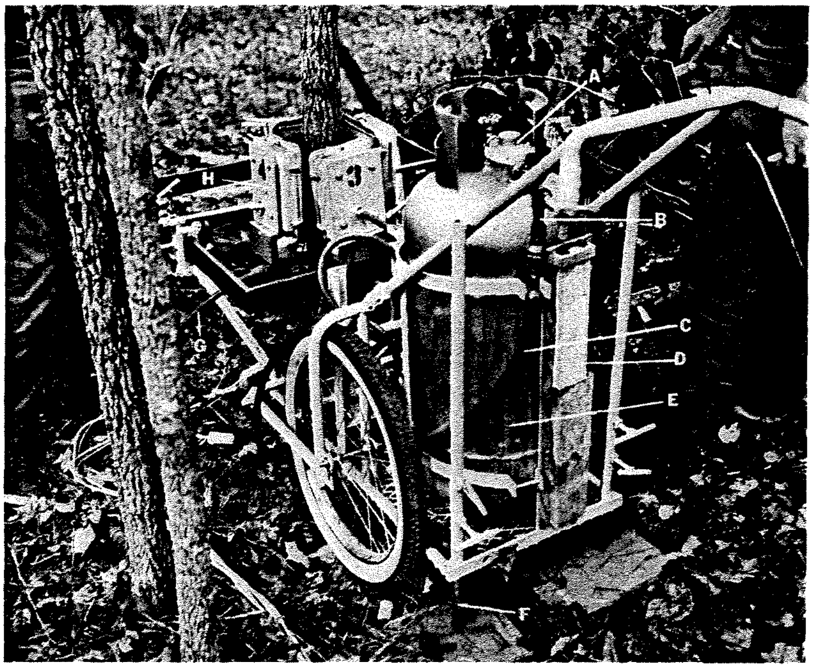

Figure 1. --Mobile heat applicator in position for field test: (A) Pressure regulator, (B) Orifice, (C) Main hose, (D) Manometer, (E) Cylinder of liquefied propane gas, (F) Rear stabilizing rod, (G) Hose for individual heater, and (H) Head of infrared heater.

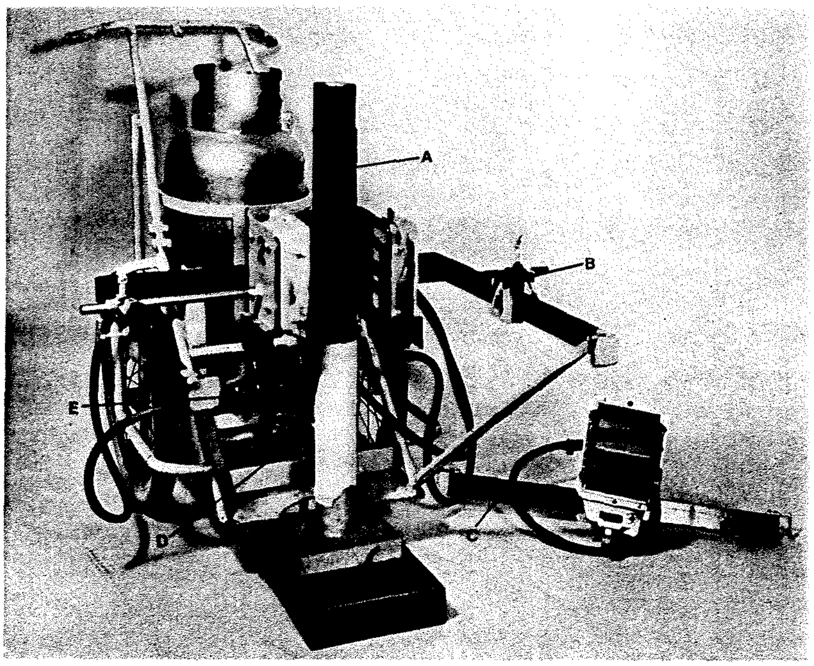

Figure 2. --Front view of mobile heat applicator with front slide frame removed to accommodate encircling the tree: (A) Calibrating calorimeter, (B) Adjustment slides, (C) Front slide frame, (D) Front stabilizing rod, and (E) Manifold for gas dispersion.

12-inch-long sections of thin-walled copper pipe 2, 3, and 4 inches in diameter; Type II consisted of a single calorimeter made from 0.01-inch-thick brass tubing 3 inches in diameter and 7 inches long. The exposed surfaces of both types were painted flat black. The Type I calorimeters were used for the initial calibration. The Type II calorimeter was developed to relate the heat output generated by prescribed fires to the output from the infrared heaters.

Because the Type II calorimeter was 7 inches long, it was totally exposed to radiant heat from the 8-inch-high heads of the infrared heaters. The temperature of the water contained in the calorimeter was monitored continuously during heat application to obtain a record of heat absorption. A detachable, battery-powered stirrer for circulating the water was housed in an asbestos-covered cylinder of similar dimensions and attached to the top of the calorimeter. Thus, the configuration of the calorimeter and stirrer assemblies resembled a portion of a tree bole with a diameter of 3 inches. Asbestos insulators were placed above and below the calorimeter to retard heat exchange through these surfaces. A surface area of 66.1 square inches was exposed to the radiant and convective heat. For the Type II calorimeter, the heat capacity of the water and brass totaled 1.72 B. t.u. for each degree Fahrenheit. Thus, the intensity of heat application (I) with units (B. t.u.) $(\text{in.})^{-2}$ $(\text{min.})^{-1}$ could be expressed by the equation

$$I = \frac{T(1.72 \text{ B. t.u./°F.})}{t(66.1 \text{ in.}^2)}$$

where T is the difference in temperature (measured in degrees Fahrenheit) between the beginning and end of the time period t, 1.72 B. t. u./°F. is a calorimeter constant, t is the length of time in minutes for which the temperature is measured, and 66.1 $\text{in.}^2$ is a calorimeter constant. The difference in heat absorbed by the Type I and Type II calorimeters was empirically determined to vary according to the equation

$$Y = 0.44 + 0.60\, y'$$

where y is the heat absorbed by the calorimeter 7 inches long, and $y'$ is the heat absorbed by the calorimeter 12 inches long.

Tests with the two types of calorimeters indicated that, within acceptable limits, the infrared heaters could be used for simulating the conditions of prescribed fires. This possibility was verified by placing a Type II calorimeter in fuel beds of loblolly pine litter while burning the beds under controlled conditions. Then these results were compared to those obtained by placing the same calorimeter in the geometric center of the four infrared heaters, much as a tree stem would be exposed.

The calibration of the infrared heaters was accomplished by using the Type II calorimeter as a standard. The intensity of heat generated was controlled by changing the discharge pressure (measured in inches of water with a manometer attached to the LPG tank) with the gas-pressure regulator and restricting the orifice through which the gas was discharged. Usable intensities of applied heat were reproducible from 0.95 to 1.65 B.t.u./sq. in./min. (fig. 3). The Type I calorimeters were used to test the effect stem diameter had on available heat reaching the stem surface. We concluded from the data derived that the same settings of pressure and orifice opening would produce approximately the same intensity of available heat at the stem surface for the three diameter classes treated, Because the heat source was radiant energy, changes in distance from the surface of the burner head to the stem did not result in intensity variations for different stem diameters.

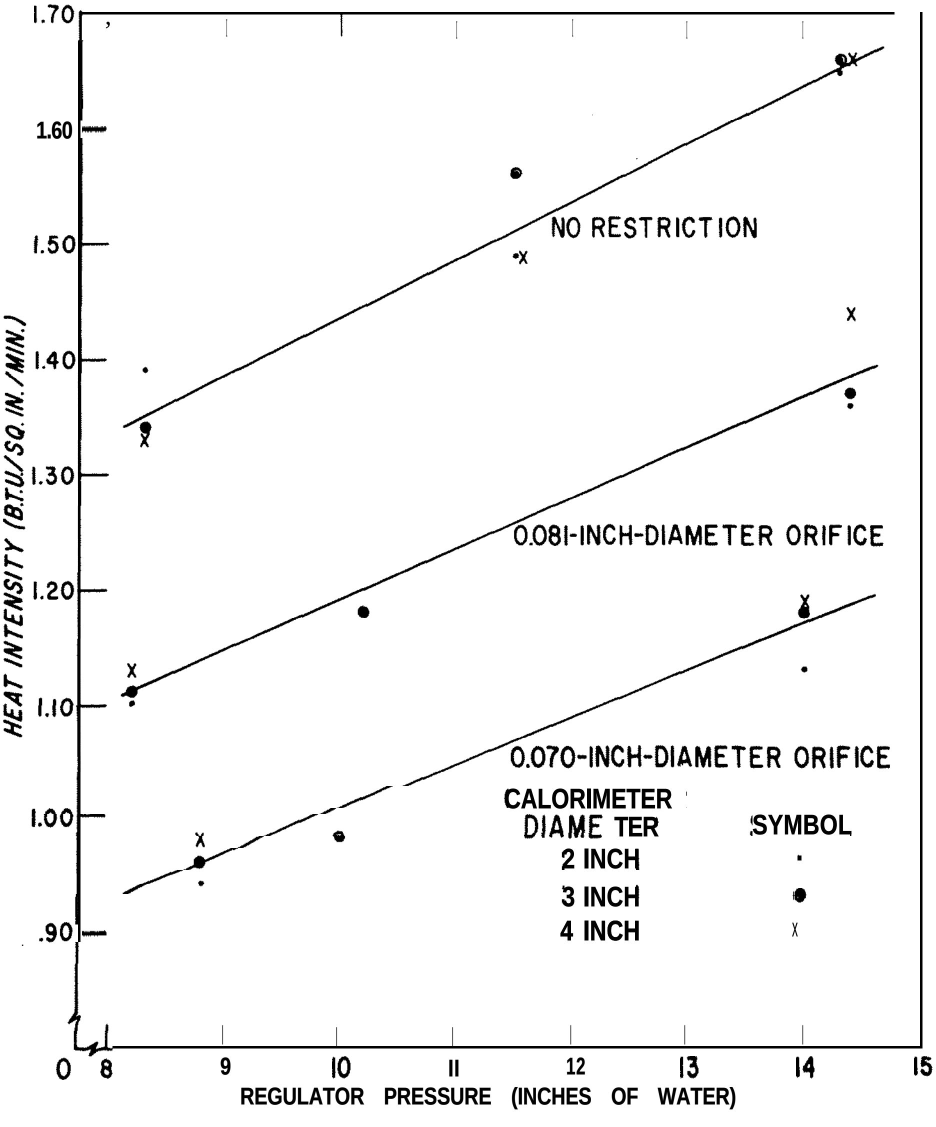

Figure 3.--Alteration in heat produced by changing the orifice size and adjusting the discharge pressure of the gas. The heat intensities were measured with the Type I calorimeter and then adjusted according to the equation y = 0.44 + 0.60 y′ to correspond with the measurements from the Type II calorimeter.

Test fires in the laboratory indicated that the heat absorbed by the calorimeter was a linear function of fuel loading. Six fuel beds, each 3 by 4 feet, were burned, and fuel loading ranged from 0.1 to 0.5 pound per square foot. These loading rates are comparable to a range of from 2.2 to 10.5 tons of available litter per acre. The beds were burned by igniting one end of the bed under no-wind conditions. Fuel moisture was held constant at 10 percent, relative humidity at 45 percent, and temperature of the combustion room at 75” to 80” F. The regression line for the six burns could be expressed by the equation $y = 0.215 + 5.875X$, where y is the quantity of heat absorbed with units B. t. u./sq. in. and X is fuel loading in lb./sq. ft.

Rate of heat absorption by the calorimeter was variable during the passage of the fire front (fig. 4). Precise simulation of prescribed fires

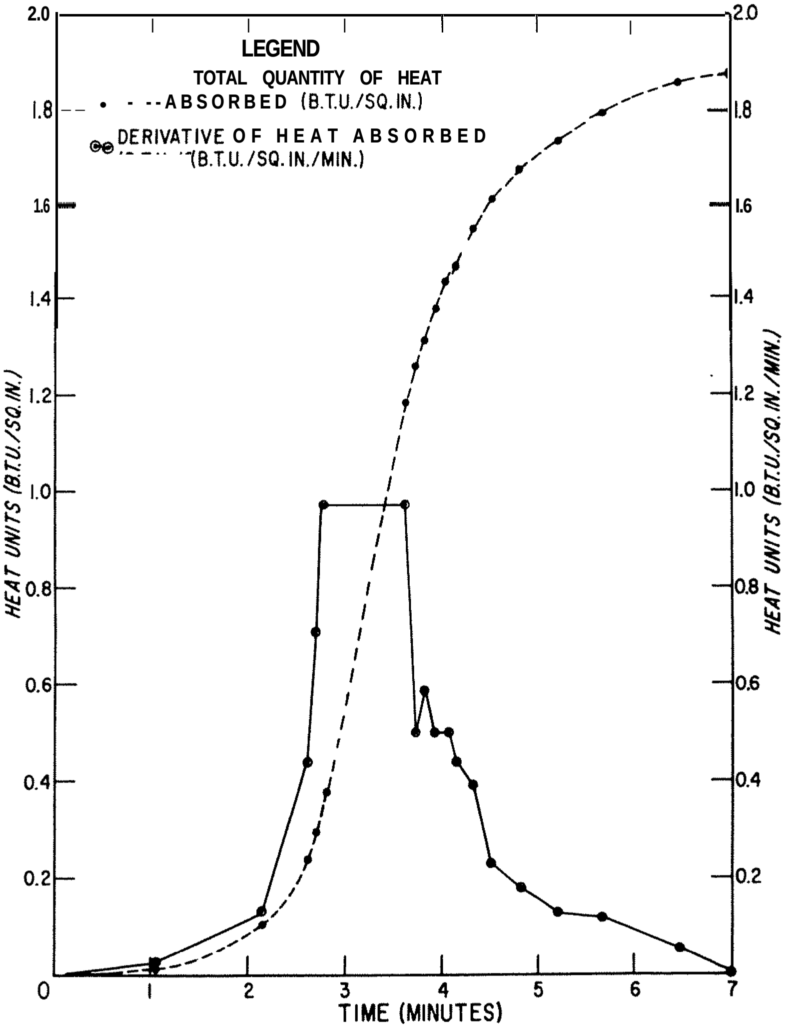

Figure 4. --Total quantity of heat output for one of the test fires and the derivative of heat output as a function of time during the time of fire passage.

is thus quite complicated, and the use of an artificial heat source to generate the range of intensities produced while burning this bed of fuel would be difficult. Therefore, in our field study, the infrared heater was used to apply heat at three rates--one for each intensity (1.0, 1.3, and 1.6 B.t.u./sq. in./min.). Heat at each intensity was applied to different trees for three time periods (0.5, 1.0, and 1.5 minutes), thus producing nine combinations of intensity and time. The range of intensities generated for one fuel bed burned is shown in figure 4. This fuel bed produced a total of 1.87 B. t.u. of heat per square inch of calorimeter surface area. This total is comparable to applying an intensity of 1.60 B. t. u./sq. in./min. for 1.17 minutes with the infrared heaters, or 1.00 B. t.u./sq. in./min. for 1.87 minutes.

The rate of LPG usage for producing different quantities of available heat at the stem surface was not proportional to these quantities of heat. Identical settings to those used for producing heat intensities of 1.0, 1.3, and 1.6 B. t.u./sq. in./min. were repeated with the LPG bottle resting on a load-cell (weight transducer). A continuous tracing of weight loss for LPG was derived and compared to the rate of increase in water temperature inside the Type II water-filled calorimeter. The water temperature increased at a steady rate from ambient to near the boiling point of water (fig. 5). The rate of LPG usage (in grams per minute) was also constant: 12.25 for the 1.0 B. t.u./sq. in./min. rate of heat application, 14.25 for the 1.3 rate, and 18.25 for the 1.6 rate. Proportionally more LPG was required to produce an additional equal amount of usable surface heat between 1.3 and 1.6 B. t.u./sq. in./min. than between 1.0 and 1.3 B. t.u./sq. in./min. No doubt this variation is related to burner efficiency for these rates of heat production.

The temperature along the stem exposed to the 8-inch-long heaters was measured with thermocouples to determine longitudinal variation in surface temperature. The highest temperatures were measured in a

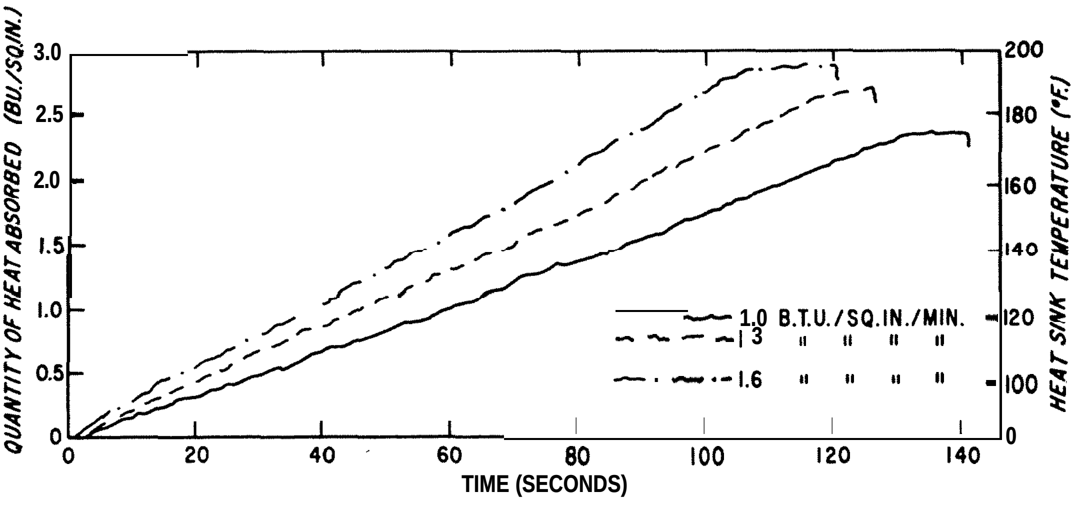

Figure 5.--Rate of heat absorption by the Type II calorimeter as a function of time for the three intensity settings.

2-inch-wide band centered 5 inches above the heater base. We recognized that some longitudinal transfer of heat away from the treated area occurred; but, from evidence compiled by inserting thermocouple probes along the cambium of sweetgum trees at different heights, the effect was found to be minimal.

## USE OF THE APPLICATOR

To date, 250 trees have received artificial heat treatment in the field, half during the winter dormant season and half during the late-spring growing season. It would have been difficult to accomplish this task by burning natural fuels placed around the tree boles. The heat applicator described has worked well for the purpose for which it was designed--that of applying reproducible quantities of heat to living tree stems to determine degrees of heat resistance, measure resulting damage, and predict tree mortality from simulated prescribed fires.

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