

Apparatus for Determining Glowing Combustibility of Thin Fuels*

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(Received Nov. 2, 1970)

Leaflike samples, approximately 8 cm in diameter, are held at the end of a mechanical arm which reproducibly controls sample movement during the ignition and burning process. Glowing combustion is induced by bringing the sample into contact with a small loop in an electrically heated nichrome wire. The ultimate burned-out area is measured in an ultraviolet detection system utilizing a vacuum photodiode. The system, calibrated using black construction paper with a series of standard holes in the range 0.002 to 20 cm², has a sensitivity close to 5 mv/cm².

INTRODUCTION

Even a cursory glance at most phases of the fire problem reveals a crying need for appropriate test procedures. For example, numerous procedures for evaluating the combustibility of building materials have been developed and are currently in use throughout the world. An indication of how meaningful some of the current standard tests may be comes from a recent summary by Emmons [1] from which Table 1 has been extracted. This table presents the numerical ratings (1—Most Combustible, 24—Least Combustible) given by investigators in six European countries to several of the 24 materials sent them for comparison. As may be seen, agreement is so poor that materials which are rated most combustible in one country may be rated least combustible in another.

At least part of the difficulty in establishing meaningful fire rating tests comes from the fact that, because of competing sequences of chemical reactions whose proportions depend on such factors as heating rate, many important fuels can "burn" in either of two different ways; i.e. by flaming or by glowing [2]. Consequently, it appears likely that before comparisons of various fire retardant treatments, for example, can have any real significance, it will be necessary to develop tests which take cognizance of the important differences between flaming and glowing combustion.

* Based on a paper presented at the 1969 Fall Meeting of the Western States Section/The Combustion Institute, San Diego, California, October 27-28, 1969.

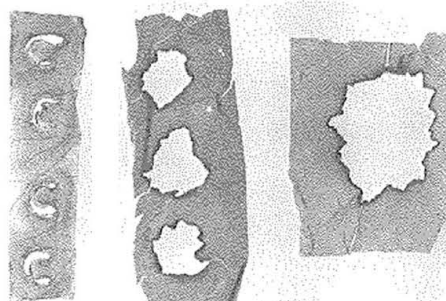


Figure 1. Typical "leaf-burn" results on tobacco, showing the ultimate burn areas for no ignition (left), 5-second leaf burns (center), and a 15-second leaf burn (right).

One industry which, for years, has been concerned with the problems of glowing combustion is the tobacco industry. An important property of leaf tobacco is the length of time it will glow after being ignited. Simple "leaf-burn" or "fire-holding capacity" tests, e.g., bringing a sample briefly into contact with a small loop in a glowing nichrome wire (Figure 1) and measuring the time of glowing combustion, have found wide utility [3]. Such tests, mechanized in order to standardize system variables and thus to increase reproducibility and accuracy, should similarly be useful for determining the relative susceptibility to glowing combustion of thin samples of cellulosic fuels treated with various inorganic "fire retardants".

This paper describes an apparatus which measures ultimate burn area rather than burn time on leaflike samples ignited and burned under carefully controlled conditions.

Table 1. Relative Rating of 24 Materials by 6 Different National Standard Fire Rating Tests.*

Material	Germany	Belgium	Denmark	France	Nether-lands	England
Expanded Polystyrene	15	1	4	17	21	1
Acrylic sheet	3	2	22	1	7	22
Wood wool/cement slab	18	23.5	23	24	24	24
Phenolic Foam	24	23.5	1	21	19	19

* Extracted from Table 2 of Emmons [1].

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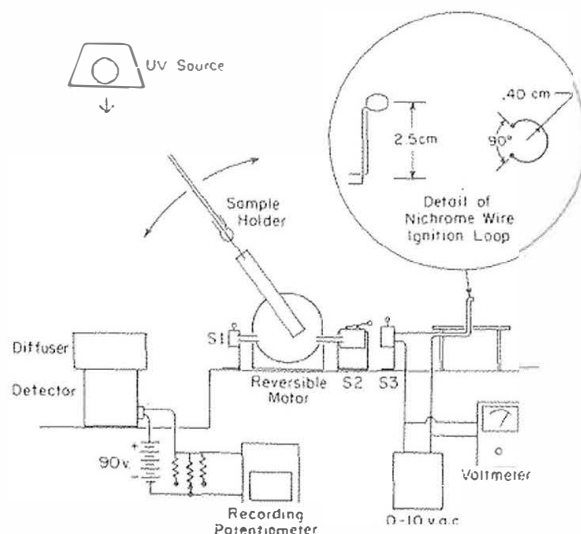


Figure 2. Schematic of "leaf-burn tester".

APPARATUS

The "leaf-burn tester" (Figure 2) includes (1) a variable temperature igniter, (2) an ultraviolet detection system for measurement of burned-out area, and (3) a sample holder, reversible motor, and associated circuitry for the control of sample movement. All components except the variable power supply for the igniter and the output recorder are housed in a box approximately 50 by 50 by 30 cm, fabricated from sheet aluminum, 1.3 mm (.050 in.) thick and painted flat black inside. A 1KVA Sorensen line regulator provides a.c. power.

Igniter

As a reproducible means of initiating glowing combustion, an electrically heated nichrome wire loop (detail in Figure 2) was chosen as the ignition source. To provide reasonable resistance to deformation or displacement, a 0.64-mm (0.025 in.) diameter wire, 10 cm in length, was selected. A loop diameter of 0.8 cm with an arc of 270° was found to provide sufficient heat reinforcement within the ignited area for the glowing ignition to have a reasonable chance of sustaining itself. The ends of the ignition wire were fitted with solderless lugs to facilitate replacement. The loop was mounted through a hole in a 10-cm square piece of Transite whose height was adjustable to permit changes in the contact geometry between sample and ignition loop.

Adjustability of igniter temperature was desirable so that different types of fuels could be tested. Consequently, power for the ignition loop was obtained from a variable autotransformer and the voltage monitored on an AC voltmeter. It was found that a setting of 2.8 volts raised the loop temperature to

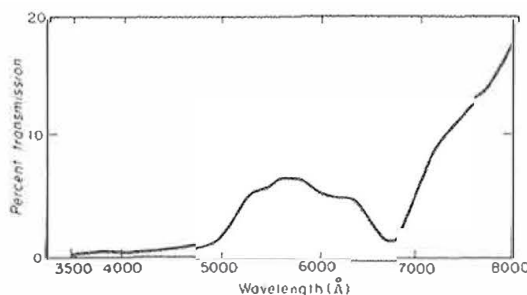


Figure 3. Typical transmission curve for tobacco leaf in the near-ultraviolet and visible region.

760°C as measured with an optical pyrometer. This proved to be a satisfactory ignition temperature for many samples of interest.

Detection System

Even in such homogeneous materials as filter paper, the area burned out in a slow glowing process is quite irregular in shape. In such non-homogeneous material as tobacco leaves (with veins, flaws, etc.) the shape of the burned-out area is extremely irregular, and thus, difficult to measure accurately by conventional means. However, if a sample is interposed between matched light source and detector, and if the sample is opaque in the pertinent spectral region, then with appropriate optics the signal received by the detector provides a measure of the size of the hole regardless of its shape.

Figure 3 shows a typical transmission curve obtained on a Cary Model 11M Recording Spectrophotometer for a representative tobacco leaf. As may be seen, such leaves are quite opaque in the near ultraviolet region. Consequently, an ultraviolet lamp, Blak-Ray Model BLF-6, with an output maximum at 3600 Å, was chosen as a light source. An RCA 934 vacuum photodiode, having an S4 response (maximum around 4000 Å) was chosen as the detection element.*

A diffusion system (Figure 4) placed between the sample and the photodiode increased the effective photosensitive area and rendered output relatively independent of hole shape and position (see calibration section). The diffuser was constructed from cardboard and was painted black on the outside and lined inside with aluminum foil.** After several more or less unsatisfactory experiments with first single, and then double layers of ground glass, it was found that diffusing elements of whiteflash glass, flashed on both sides, produced a highly-uniform, diffuse signal to the phototube.

* The gallium arsenide photocell originally selected was replaced since the advantage of its larger area of uniform photosensitivity was outweighed by the disadvantages of relative insensitivity (about 20 percent that of the phototube) and larger temperature coefficient (2.5 times that of the phototube).

** See footnote, p. 82.

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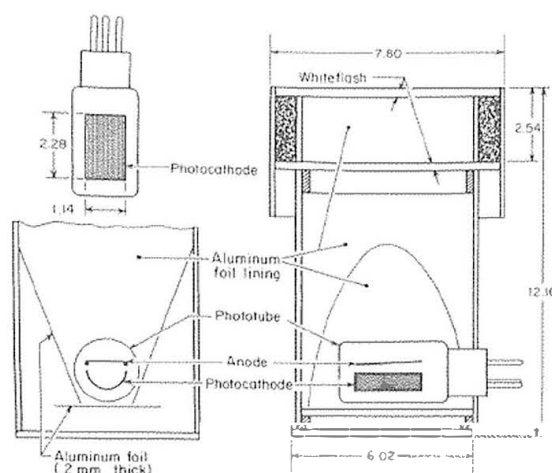


Figure 4. Cross-section of diffuser and detector.

Cathode-anode potential to the phototube was supplied from a 90-volt "B" battery which provided an operating voltage well within the linear active region of the tube. The output was taken as the voltage across a 243 kohm precision resistor in series with the photodiode. Two alternate resistances, 121 kohms or 48.7 kohms, could be chosen by a rotary switch. These provided range multiplication factors of 1.81 or 4.23 times the basic voltage. When used in conjunction with the 1, 10, or 100 mv ranges of a Moseley 7100B strip chart recorder, ultimate burn areas between 10^{-3} and 20 cm^2 were measured accurately.

Sample Holder and Control System

Leaflike samples are inserted between two spring-hinged aluminum rings, 1.3 mm thick and with a 6 cm I.D., attached to the end of a 14 cm aluminum arm. The arm is mounted on the shaft of a reversible motor, which is controlled by microswitches placed in the path of travel of the arm. The switches, labeled S-1 through S-3 in Figure 1, function as follows. A sample is loaded with the arm in a horizontal position over the detector and a reference reading taken. Power is then turned on, and the arm moves in a clockwise direction until the sample nears contact with the ignition loop. Switch S-3 (spring-loaded and normally closed) is in the power line to the ignition loop and opens that circuit just as the sample contacts the loop. The ignition loop cools rapidly and reproducibly, thus providing a short, reproducible contact time and minimizing the chance of flaming ignition of the pyrolysis products by a still red-hot wire. Switch S-2, operated simultaneously with switch S-3, reverses the motor polarity, causing the sample to move counterclockwise toward the detector. Johnson et al. [3] reported the significant upper time limit for leaf burn in tobacco to be 20 sec. Since the sample holder sweeps

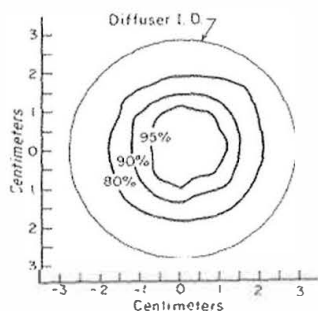


Figure 5. Contour lines of phototube output for a small aperture moved about the top plane of the diffuser.

through a 180° arc in moving from igniter to detector, a motor speed of 1 rpm was chosen to provide up to 30 seconds of burning time under relatively constant conditions. Movement of the sample during this time corresponds to a gentle breeze of 1.8 cm per second (0.04 mph). When a horizontal position over the detector is reached, the arm operates switch S-1 which cuts power to the motor, leaving the sample in position for measurement of burned-out area.

CALIBRATION AND USE

Uniformity

Before calibrating the detector output as a function of hole size, some preliminary checks were made of variation of signal with time, position, and temperature. For this purpose, a square hole 0.0723 cm^2 in area, was cut in a 15-cm square piece of 0.2-mm black construction paper and centered over the detector. After a one-hour lamp warmup time, the output trace was found to remain constant for periods of hours at constant temperature. The 95, 90, and 80 percent contour lines on the top plane of the diffuser, i.e., the area within which the hole may be moved before the signal falls below that percentage of its peak value, are shown in Figure 5.* By operating the equipment in an environmental chamber, the output was found to have an approximately linear temperature dependence over the range 15 to 35°C , with a temperature coefficient of $-1.0\% / ^\circ\text{C}$ at 25°C .

Calibration

An additional series of standard holes, carefully measured under an eyepiece micrometer, were cut in 10-cm square pieces of the black construction paper. The standards included 11 circular holes ranging from 0.96 to 5.0 cm in diameter and 21 square holes ranging from 0.05 to 4.0 cm on a side. As a further check on the effect of highly asymmetric hole shape, three oblong holes, with length approximately 10 times width, were cut with lengths of 1.0, 2.0, and 3.0 cm. Thus, the standard areas ranged from $.0024$ to 20 cm^2 .

A plot of hole area as a function of millivolt output is given in Figure 6. Each point represents the mean of six readings with the standards replaced in random sequence for each reading. Over the entire range a least-squares fit to the data yielded the quadratic regression:

* Preliminary experiments indicate that by replacing the aluminum foil liner with a diffuse reflector, e.g. a magnesium oxide coating, the area within each of these contour lines can be increased by more than 50 percent.

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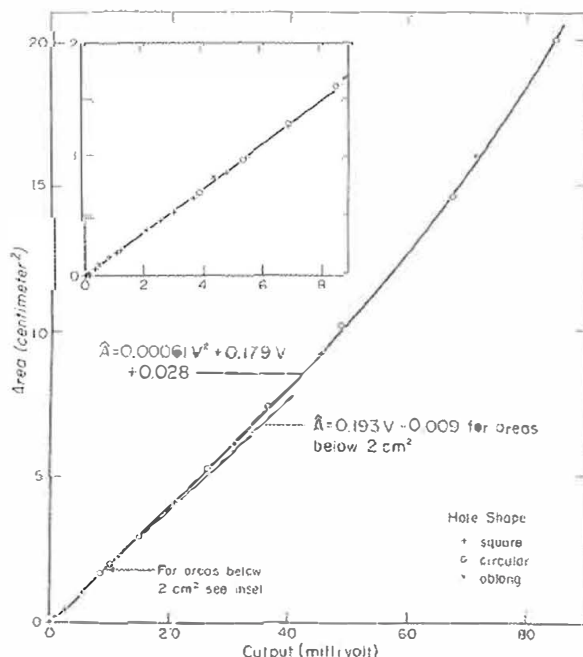


Figure 6. Calibration curve of aperture area vs. phototube output.

$$A = 0.00061V^2 + 0.179V + 0.028$$

with a third order term not significant at the 90% level. For areas under 2 cm² the linear regression,

$$A = 0.193V - 0.009$$

shown as the fine line in Figure 6, is satisfactory.

The least-squares curves were not required to pass through the origin, since light leakage into the detector and the dark current of the phototube both result in a positive signal with a blank shield in place. Turning off the lamp and carefully sealing the detector reduced the "zero" signal by some 90 percent, indicating that it is mostly due to leakage. The residual signal, corresponding to a dark current of only 2×10^{-11} A, was well within manufacturer's specifications.

Use

To illustrate the utility of the apparatus, a series of filter papers were treated with 1 ml each of increasing concentrations of KHCO₃ solution. Since, unlike tobacco leaves, the white filter papers are somewhat transparent in the critical spectral region, the dried papers were spray painted flat black on one

side (Rust-Oleum 412), redried, and tested (Figure 7 and Table 2). As may be seen, the results are quite reproducible. For the untreated samples, the areas correspond to "branding" by the igniter—with essentially no further spread. Between 0.4 percent and 1.7 percent impregnation, sustained glowing did occur but stopped before reaching the aluminum holder. At 3 percent at least part of the burn is interrupted by the holder. With 7 percent impregnation, the entire exposure area burns out. It is interesting to note that samples impregnated with 14 percent KHCO_3 are again not entirely consumed.

CONCLUSIONS

An electrically heated nichrome wire appears to provide a convenient and reproducible method for inducing glowing combustion in such fuels as tobacco leaves or blackened filter paper impregnated with KHCO_3 . Even irregularly shaped areas burned through such fuels may be measured accurately with an ultraviolet source and a vacuum photodiode detector, if the radiation transmitted through the burn hole is well diffused.

Table 2. Reproducibility of Burn Areas Measured on KHCO_3 —impregnated filter paper.*

Sample No.	KHCO_3 Treatment (% of original wt.)	Output (mv)	Burn area (cm^2)
1	0	.409	.068
2	0	.441	.074
3	0	.414	.069
4	0	.442	.074
5	0.42	1.03	.187
6	0.42	1.21	.221
7	0.42	1.16	.212
8	0.42	1.24	.227
9	0.85	1.90	.354
10	0.85	1.84	.342
11	0.85	2.12	.396
12	0.85	2.13	.398
13	1.70	3.61	.682
14	1.70	3.14	.592
15	1.70	3.19	.602
16	1.70	3.16	.596
17	3.4	36.90	7.40
18	3.4	40.02	8.03
19	3.4	28.80	5.77
20	6.8	92.88	Off
21	6.8	97.70	Scale
22	13.6	65.45	14.2
23	13.6	85.33	20.3

* See Figure 7.

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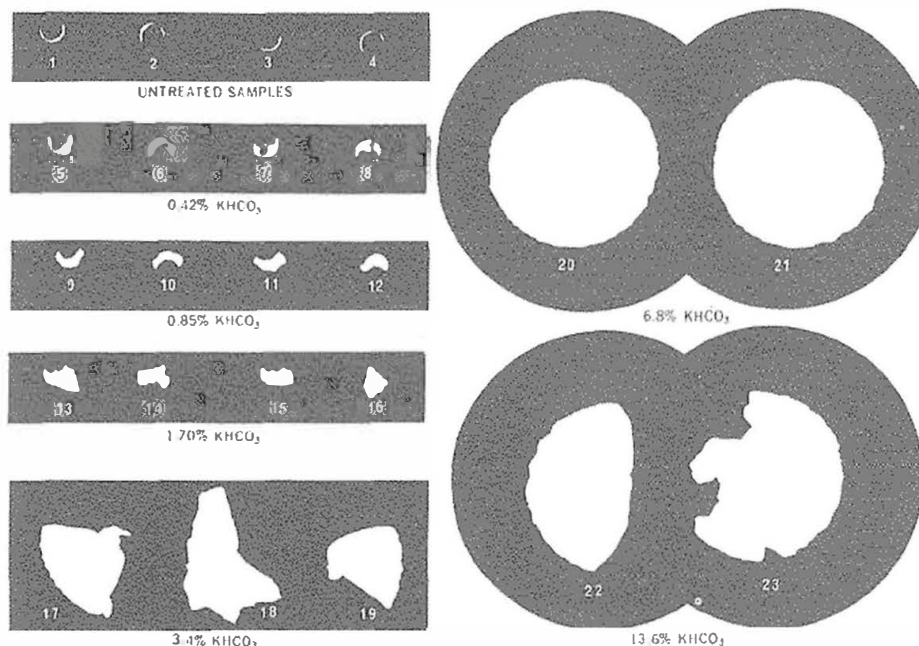


Figure 7. Examples of reproducibility obtained with the apparatus: blackened filter papers impregnated with KHC0_3 .

ACKNOWLEDGMENTS

We thank Charles F. Wojslaw for his help in the design and fabrication of an earlier model of this apparatus.

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