DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THE SPREAD OF FLAME ALONG VERTICALLY HANGING FABRICS

by

D. I. Lawson

September, 1954.

Fire Research Station,
Boreham Wood,
Herts.

THE SPREAD OF FLAME ALONG VERTICALLY HANGING FABRICS

by

D. I. Lawson

Introduction

Materials generally propagate flame most rapidly when hanging vertically. It has been reported [1] that an empirical relation shows the vertical speed of burning for cellulosic materials such as paper, wood veneers and cotton to be inversely proportional to the weight per unit area.

Analysis

If a fabric of thickness l is immersed in flame heat will be transferred to the fabric ahead of the material which is burning; the temperature of this will rise until it is able to give off combustible gases; these will ignite, and the flame front will move forward. The velocity of the flame front will depend inversely on the time necessary for the temperature of the material to rise to the point of ignition.

In making an analysis several simplifying assumptions must be made.

(1) That the material is homogeneous and that the usual thermal constants K, s, and ρ can be specified for it.

(2) That the material will always ignite when its temperature has risen to some value V_i irrespective of the thermal history of the material.

(3) That the material behaves as an inert body up to the time of ignition.

(4) That the heat transfer from the flame to the material can be represented as $H(V-v)$ where v is the temperature of the material and V is the temperature of the flame.

The temperature v at any point x in a solid occupying the region $-l < x < l$ and receiving "radiation" from a medium at temperature V is given [2]

$$v = 2kh\sum_{1}^{\infty}\frac{\alpha_n^2 e^{-k\alpha_n^2 t}\cos\alpha_n x}{\{h + l(\alpha_n^2+h^2)\}\cos\alpha_n l}\int_0^t V e^{k\alpha_n^2\lambda}\,d\lambda \qquad \text{........ (1)}$$

where α_n are the roots of $\alpha\tan\alpha l = h$ .... (2)

$h = \frac{H}{K}$

K is the thermal conductivity of the material
k is the thermal diffusivity of the material

The surface temperature V_s is found by substituting $x = \pm l$ in (1)

$$V_s = 2hV\sum_{1}^{\infty}\frac{1-e^{-k\alpha_n^2 t}}{h + l(\alpha_n^2+h^2)} \qquad \text{........ (3)}$$

If l the semi-thickness of the fabric is small and since h will have values of the order of 0·15 only the first root of (2) will be significant when substituted in (3).

From 2 $\alpha_1^2 = \frac{h}{l}$

Which on being substituted in (3) gives

$$v_s = \frac{2hV\left[1 - e^{-\frac{kh}{l}t}\right]}{2h\left[1 + \frac{hl}{2}\right]}$$

$$\simeq V\left[1 - e^{-\frac{kht}{l}}\right]$$

If the material ignites when some surface temperature V_i has been reached this will occur at a time t given by

$$V_i = V\left[1 - e^{\frac{kht}{l}}\right] \qquad \ldots\ldots\ldots (4)$$

The time t at which ignition takes place is related to k, h and such that

$\frac{kht}{l}$ is a constant say C

$$\therefore\ t = \frac{lC}{kh} = \frac{l\rho sC}{H}$$

= Wt/unit area s and H being constant for any given material e.g. cellulose. Hence velocity of flame front $\propto$ $^1/$weight per unit area. It is interesting to pursue the relation for the time of ignition given in (4), this may be expressed as

$$\log \frac{V}{V - V_i} = \frac{kht}{l}$$

Since v represents the flame temperature (say about 1,000°C) and v_1 the temperature for ignition in the presence of a flame (about 250°C) so that $V > v_1$ then roughly

$$\frac{V_i}{V} = \frac{kht}{l} = \frac{Ht}{l\rho s}$$

$$\text{or}\quad \frac{l\rho}{t} = \frac{V}{V_i}\,\frac{H}{S}$$

Now if a characteristic distance $\mathcal{X}$ is introduced into both sides of the equation such that $\mathcal{X}$ has the physical significance of being the distance ahead of the flame at which heating just begins

$l \rho x/t$ is the constant Wt./area x velocity of flame front which has been found (3) to be 80 x 10^{-3} gm cm^{-1} sec^{-1}.

Putting v = 1,000°C
v_1 = 250°C
H = 2·6 x 10^{-4} cal cm^{-2} sec^{-1} $°C^{-1}$ (4)
S = 0·4 cal/gm

gives a value for x of about 30 cm.

In spite of the rather crude assumptions which have been made the above value is reasonable.

Bibliography

(1) Lawson, Webster and Gregsten. The flammability of fabrics. F.R. Note No. 107/1954.

(2) Carslaw and Jaeger. Conduction of heat in solids. Page 102. Clarenden Press, 1948.

(3) Lawson, Webster and Gregsten. loc. cit.

(4) Lawson, Webster and Fox. The heating of panels by flue pipes. H.M.S.O. Special Report No. 1, 1952.