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IGNITION OF DUST LAYERS ON HOT SURFACES

by

P.C. Bowes, M.D. Harris and Miss S.E. Townshend

SUMMARY

The minimum temperatures for ignition of beech
sawdust layers on a hot surface have been determined
for range of depths, densities, and particle sizes
of the dust.

The results have been correlated by a thermal
ignition theory.

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INTRODUCTION

Combustible dusts in contact with a hot surface will ignite if the temperature of the surface is high enough and fire or explosion may result. Examples are the ignition of combustible dusts on overheated bearings[1], on exposed steam pipes or steam pipe flanges[2] and on unprotected electric light bulbs[3]. The hazard has recently become of interest in connection with the safe running temperatures for electrical equipment in dust-laden atmospheres or in situations where dust may accumulate on surfaces.

Palmer and Tonkin[4], Hardy[1], and Freytag[5] have determined the minimum temperature at which a hot surface can ignite deposits of some coal dusts, cork dust, and wood sawdust, and have shown that this minimum temperature depends markedly on the thickness of the deposit of a given dust.

The work described in this note extends that of Palmer and Tonkin on the effect of depth, particle size, and packing density on the minimum temperature for ignition of wood sawdust on a hot surface. Correlation of the results on a theoretical basis is attempted.

EXPERIMENTAL

Material

Beech sawdust, separated by sieving into the particle size ranges given in Table 1, was used in these tests. Beech was chosen because different size fractions of the sawdust are unlikely to differ widely in composition or in the form of the particles.

The average moisture content of the sawdust was 11 per cent.

Apparatus

The apparatus was similar in principle to that used by Palmer and Tonkin[4]. The hot surface on which the ignition tests were carried out was a horizontal plane circular plate of aluminium alloy 19 cm in diameter and 0.64 cm thick. It was heated electrically on the underside and was controlled to run at any desired temperature to within about 1°C. Some thermal insulation was provided round the periphery of the plate.

The temperature control system, the sensing element of which was a thermocouple fixed in the underside of the plate near the centre, was set by reference to a potentiometer at the beginning of each test and was checked again at the end of each test. The drift was less than 1°C. A second thermocouple on the underside of the plate was used to obtain a continuous record of the plate temperature.

A chromel-alumel thermocouple, 36 S.W.G., for following the course of ignition was stretched across the plate with its junction over the centre. The distance of the junction from the plate was adjustable and was arranged to be inside the dust deposit and, in most cases, just below its centre plane.

Procedure

Except for tests on layers of less than 5 mm in depth, the general procedure for ignition tests was as follows:-

A dust layer was formed on the plate, at room temperature, in a cylindrical mould of appropriate height and diameter (see below). After removing the mould

the plate was heated up to a pre-determined temperature. The time taken
to reach this temperature was about 15 minutes.

A test was continued until a layer ignited and a zone of smouldering
combustion appeared on the surface, or until it was clear that no ignition
would occur. Failure to ignite was shown by the temperature in the dust
deposit increasing to a maximum and then decreasing.

The densities of dust deposits prepared without compression was
usually within $\pm$ 0.01 g/cm3 of the mean for deposits of given depth.

In preparing deposits of high density the sawdust was compressed, by
hand, by means of circular plates fitting inside the moulds.

Some tests with layers having different ratios of diameter to height
indicated that provided this ratio was greater than 5 it had little effect
on ignition temperature. Smaller values of the ratio resulted in an increase
in the ignition temperature for a deposit of given depth. Except for the
deposits 25 mm in depth, for which the diameter/depth ratio was 5, the ratio
was greater than 5 in all tests described in this note.

For reasons described below, tests with layers of 3 mm depth were
carried out by depositing the dust on to the plate already preheated to the
test temperature. The time taken to deposit the dust in these tests, and
to spread it uniformly within the mould, was less than 20 seconds. The mould
was left in place throughout the test.

Definition of ignition temperature

Ignition tests were made at hot surface temperatures differing by
intervals of 5°C. The frequency with which layers of a given thickness
ignited at a given temperature varied with temperature over a range of
15-20°C. Therefore, in the main series of tests, the ignition temperature
was defined arbitrarily as that temperature at which an ignition occurred and
which was 5°C higher than the maximum temperature at which no ignition
occurred in five repeated tests. The frequency of ignition at the ignition
temperature was thus 20 per cent or more, but the number of tests at this
temperature was usually less than five.

In other series of tests, which will be indicated, the maximum temperature
for ignition failure was characterised by non-ignition in three repeated tests.
Minimum ignition temperatures determined on this basis were, as would be
expected, sometimes 5° or 10°C higher than those based on 5 non-ignitions.

RESULTS

Qualitative features of ignition

Temperature/time records typical of those obtained with the thicker
layers tested are shown in Figs. 1 and 2 respectively for a layer that ignited
and one that did not. The records show the hot plate temperature and the
temperature at a distance of 1.0 cm from the plate in a layer of 36-60 mesh
sawdust 2.5 cm thick.

The following points are of interest in the temperature record for the
layer that ignited. A pause in the rate of temperature rise in the interval
A (Fig.1) may be attributed to loss of moisture in the temperature range
60-90°C. At B the temperature in the plane 1.0 cm from the hot surface passes
through the value that would finally be reached in this plane if the sawdust
were chemically inert; this value, about 190°C, is calculated on the basis
of a thermal conductivity for the layer of 1.3 x 10^{-4} c.g.s. units (Appendix
1) and an estimated temperature for the cool surface of about 60°C. An
exothermic reaction is clearly taking place. At C there is a relatively
rapid increase in the rate of temperature rise in the neighbourhood of 250°C;

it is reminiscent of that which occurs in determinations of the ignition temperature of wood sawdust by a rising temperature method and which is used to define the ignition temperature(6). At D the slope of the temperature record passes through a maximum in the neighbourhood of 300°C, from which, neglecting possible changes of thermal capacity, it may be inferred that the rate of heat evolution per unit volume passes through a maximum at 300°C in the plane 1 cm from the hot surface. At E, which corresponds in time to the appearance of smouldering at the top surface of the layer of sawdust, the temperature begins to rise again. This indicates an increase in the rate of heat evolution, and is probably a consequence of increased air access to the interior of the layer following the emergence of smouldering.

When ignition (Fig.2) does not occur the temperature in the plane 1 cm from the hot surface rises to a maximum, in this case about 30°C above the value that would exist in this plane in the absence of reaction, and then decreases.

In thinner layers, e.g. 1 cm, the sequence of events occurred within a shorter time and the decrease in the rate of temperature rise immediately preceding the breakthrough of smouldering was not always observed. Occasionally ignition occurred to one side of the centre of a layer, and was therefore not indicated in the temperature record until smouldering had spread to the centre; this was more often so for the thinnest layers tested (5 mm and less).

Tests with layers of less than 5 mm thickness were carried out with the finer fractions only. Layers 3 mm in thickness could not be ignited when heated on the plate from room temperature up to a temperature as high as 410°C for the 60-120 B.S. sawdust fraction. Decomposition of the sawdust occurred with an evolution of volatiles which practically stopped before the assigned plate temperature was reached. When, however, a 3 mm layer was formed quickly on the plate already preheated to a steady temperature, ignition of the layer occurred at a minimum plate temperature compatible with ignition temperatures for thicker layers (see below). It was subsequently shown for thicker layers, i.e. 5 mm and 10 mm, of the 18-36 B.S. fraction that the minimum plate temperature for ignition was independent of whether or not the plate was preheated to its final temperature before depositing the dust (Table 1).

Minimum ignition temperatures of dust layers

The minimum temperature of the hot surface for ignition of layers of sawdust varying in depth from 3 mm to 25 mm are given in Table 1 for four sieve fractions of the sawdust at two principal packing densities. Results for uncompressed layers of density about 0.27 are in the upper part of the table, and those for compressed layers of density about 0.4 in the lower part of the table.

Table 1

Minimum surface temperature, °C, for ignition of beech
sawdust layers on hot surface

Depth of layer, mm.			3	5	8	10	16	20	25
Sieve fraction B.S.	Nominal size range Microns	Mean density g/cm³							
18-36	853-422	0.28	-	350	-	-	-	-	-
		0.25	-	350*∮	-	-	-	-	-
		0.25	-	-	325	-	-	-	-
		0.26	-	-	-	310	-	-	-
		0.25	-	-	-	315*∮	-	-	-
		0.22	-	-	-	-	295	-	-
		0.24	-	-	-	-	-	285	270
36-60	422-251	0.28	-	340	-	-	-	-	-
		0.29	-	-	-	305	-	-	-
		0.26	-	-	-	-	-	-	275*
60-120	251-124	0.29	370*∮	-	-	-	-	-	-
		0.28	-	345	-	310	-	-	270
<120	124-0	0.29	350∮	-	-	-	-	-	-
		0.26	-	335	-	-	-	-	-
		0.27	-	-	-	300	-	-	-
		0.28	-	-	-	-	290	-	-
18-36	853-422	0.44	-	320*	-	-	-	-	-
		0.37	-	-	-	305*	-	-	-
36-60	422-251	0.44	-	325*	-	-	-	-	-
		0.38	-	-	-	305*	-	-	-
60-120	251-124	0.45	-	320*	-	-	-	-	-

*Based on 3 non-ignitions 5°C lower.

∮Layer deposited on preheated plate.

It will be seen from Table 1 that, in common with the results of other
workers, the minimum temperature for ignition decreases as the thickness of
the dust layer is increased. For the three sieve fractions in the range
18-120 B.S. the minimum ignition temperature for layers of given thickness is
within 5°C of the mean for all the fractions at that thickness and shows no
consistent trend with particle size; but for the fraction below 120 B.S. the
ignition temperature of the 3 mm and 5 mm layers, at least, is markedly reduced.
Increase of packing density leads to a decrease in ignition temperature for the
5 mm layers, but not in thicker layers. A quantitative relationship between
ignition temperature, depth and density is discussed below.

APPLICATION OF THERMAL IGNITION THEORY

General

The thermal theory of ignition, developed initially by Semenov[7] and Frank-Kamenetskii[8] for homogeneous ignition in gases, has been shown[9] to furnish a linear correlation for the results of experiments on the ignition of blocks of fibre insulating board exposed to uniform ambient temperatures in an oven.[10]. Subject to limitations indicated later the theory enables a prediction to be made of critical sizes or critical ambient temperatures for ignition due to self-heating, once certain constants for the material involved are known. It is therefore worth while to determine the extent to which the theory can be applied to the ignition of layers of dust on a hot surface.

Briefly, the theory, in the form to be applied here, sets out to define the limiting conditions for the existence of a steady-state temperature distribution in a body that is generating heat at a rate that depends on temperature and is losing heat to the surroundings. Any small departure from these conditions that tends to increase the temperature at any point in the body will lead to ignition.

Frank-Kamenetskii's[8] treatment of the problem defines the limiting conditions for a steady state or, in other words, critical conditions for ignition, by the equation

$$\frac{QF\rho \, E r^2 e^{-E/RT_A}}{KRT_A^2} = \delta_c \, , \quad \ldots\ldots\ldots\ldots\ldots(1)$$

when the rate of heat evolution per unit mass, q, at any point in the body is given by

$$q = QF e^{-E/RT} \, , \quad \ldots\ldots\ldots\ldots\ldots(2)$$

and where

Q = heat of reaction (cal g^{-1}),
F = pre-exponential factor in Arrhenius equation (s^{-1}),
E = activation energy (cal mol^{-1}),
R = gas constant (cal mol^{-1} $^{\circ}$K^{-1}),
ρ = density of body (g cm^{-3}),
K = thermal conductivity of body, assumed independent of temperature (cal s^{-1} cm^{-2} ($^{\circ}$C/cm)$^{-1}$),
r = semi-thickness of slab, or radius of infinite cylinder or of sphere to which the form of the body approximates (cm),
T_A = ambient temperature $^{\circ}$K.

The dimensionless parameter δ_c has a value that depends on the geometrical form of the body and on the cooling conditions at the surface.

The expression for the rate of heat evolution, equation (2), is based on the assumption of a first order reaction which obeys the Arrhenius equation, and in which the loss of reactant during the ignition process is small and may be neglected. This last proviso will be fulfilled to the extent that the heat of reaction, Q, is large. The factor F includes a dimensionless concentration factor.

Where, as for the ignition of dusts on a hot surface, the body is effectively a slab with one face at a constant high temperature and the other cooling to the atmosphere, the application of Frank-Kamenetskii's approach yields[11] equation (1) with T_A replaced by T_p, the temperature of the hot

surface, as the definition of critical conditions for ignition. δ_c becomes a function of the surface cooling and of the temperature difference between the hot surface and the surroundings, expressed in terms of the dimensionless quantities α and θ_o, where

$$\alpha = \frac{hr}{K} \quad \text{and} \quad \theta_o = \frac{E}{RT_p^2}(T_o - T_p) ;$$

here

h = overall coefficient of heat transfer at the boundary between the slab and the atmosphere (cal s⁻¹ cm⁻² °C⁻¹)

T_o = temperature of surroundings (°K).

This extension of Frank-Kamenetskii's approach involves the use of the exponential approximation to the Arrhenius equation in the definition of θ, outside the range of temperature differences for which it is valid, but it has been shown that the error thereby involved is small[11]. δ_c for the unsymmetrically heated slab has been tabulated and is plotted in Fig.3.

It follows from equation (1) that for dust layers of given density, and thickness 2r, igniting at minimum temperature T_p, a plot of $\log_{10}$ $(\delta_c T_p^2/r^2)$ vs. $1/T_p$ should be linear with slope $-E/2.303R$; provided, of course, that the simple reaction considered in the theory adequately represents the ignition process. δ_c is obtained from Fig.3 for values of α and θ_o appropriate to the experimental conditions. α is calculated, with sufficient accuracy, by assuming that the sawdust is inert, and θ_o is initially calculated with an assumed value for the activation energy. The above plot then yields a value for the activation energy, E, which may be used to correct θ_o and so obtain an improved value for E. Details of the calculations are given in Appendix II.

Results for the three fractions of beech sawdust between 18 and 120 B.S. are plotted in the above manner in Fig.4. The points are based on a second approximation to E of 26,000 cal. mol⁻¹ (Appendix II). The points for these three fractions do in fact lie close to a straight line. The line shown gives the following values for E and the product QF in equation (1):

E = 26,500 cal mol⁻¹
QF = 3.62 x 10⁹ cal g⁻¹ s⁻¹ (corrected for E=26,500)

Inserting the above constants in equation (2) the rate of heat evolution at 250°C is found to be 36 x 10⁻³ cal g⁻¹ s⁻¹, or 2.2 cal g⁻¹ min⁻¹. This is comparable with the value of 2.6 cal g⁻¹ min⁻¹ at 250°C estimated from determinations of the ignition temperature of beech sawdust in a furnace by a rising temperature method[12]. However, it must be pointed out that later determinations of ignition temperature by the furnace method (not yet reported) indicate that a change in the size of the specimen can alter the estimated rate of heat evolution by a factor of two or so. Activation energies obtained by this latter method tend to be about 30,000 cal mol⁻¹ for beech.

For the sieve fractions above 120 B.S., ignition appears to be independent of particle size. But for the fraction below 120 B.S., the points in Fig.4 appear to lie on a different line (chain line) which yields the following constants:-

E = 29,000 cal mol⁻¹
QF = 4.13 x 10¹⁰ cal g⁻¹ s⁻¹ (corrected for E=29,000)

The rate of heat evolution in the fine fraction at 250°C is then 2.2 cal g^{-1} min^{-1}; this happens to be the same as for the coarser fractions at this temperature.

Effect of density

A change in the packing density of the dust layers will, in general, result in a change in their thermal conductivity. Tabulated data on the thermal conductivity of sawdust is insufficient for a direct assessment of the variation with density. But assigning the bulk properties of beech to the sawdust particles it may be estimated, with the aid of an equation due to Maxwell (Appendix I), that an increase in density from 0.28 to 0.44 (as for the 5 mm layers) will increase the thermal conductivity from 1.35×10^{-4} to 2.16×10^{-4} c.g.s. units. That is, in increase in density by a factor of 1.57 increases the thermal conductivity by a factor of 1.60. Since thermal conductivity and density appear as a quotient in equation (1) the critical conditions for ignition would be independent of changes in density if the above were the only consequence of a change.

However, α, and therefore δ_c, is a function of the thermal conductivity. For the 5 mm layers of density 0.28, α was 0.85 and δ_c was 8.1. The increased thermal conductivity of the high density layers (above) reduced α to 0.57 and δ_c to 5.6. Calculated on this basis the points corresponding to the 5 mm layers of high density and particle size $\angle$ 120 B.S. lie reasonably close to the line for the corresponding low density layers in Fig.4.

For the 10 mm layers the increase in density (Table 1) decreases α from 1.48 to 1.15 and δ_c from 10.9 to 9.5. This relatively small change is reflected in the lack of significant difference between the ignition temperatures of the high and low density layers.

It thus appears that the effect of variation in the density of dust layers on the critical conditions for ignition is only of importance in thin layers for which α is small and where δ_c varies rapidly with α.

Prediction of critical depths and temperatures for ignition of dust layers

When E and QF have been determined experimentally in the above way for a given material the prediction of other critical depths and temperatures for ignition consists in finding pairs of values of T_p and r that satisfy simultaneously both equation (1) and the relation $\delta_c = F_1(\alpha, \Theta_0) = F_2(T_p, r)$ of Fig.3. This is most easily done by taking a value of T and finding the appropriate value of r by trial. E and QF will normally have been determined for fairly thin layers and a guide to the initial choice of α will thus be available. With thick layers, say 30 cm or more, α becomes large enough for variation of δ_c with α to be small and the value of δ_c then depends mainly on Θ_0; a value of δ_c of, say, 90 per cent of its value at $\alpha = \infty$ for the appropriate Θ_0 will be adequate for most purposes.

Fig.5 shows the predicted relation between depth and ignition temperature for layers of beech sawdust (sieve fractions between 18 and 120 B.S.) on a hot surface, at a density of 0.25 g cm^{-3} and cooling to surroundings at 25°C. The main practical interest of the relationship lies in the region below 200°C and with sawdust layers of a foot or more in depth. In this region it is a difficult matter to carry out experimental tests, but it is just here that information is sometimes required and, hitherto, has been completely lacking.

Possible examples range from the hazard of sawdust lagging in the walls or on the roof of a drying room or kiln to the risk of ignition in large stocks of sawdust stored on a floor over a boiler room.

It must be emphasised that an extrapolation of the magnitude attempted in Fig.5 must be treated with reservation until more is known of the true kinetics of the self-heating and ignition reactions and of their effect in modifying the theory, or until data on large scale examples of ignition is available as a check.

Thomas(9) has already pointed out that a discrepancy appears when thermal ignition theory based on the simple reaction mechanism assumed here is applied to Mitchells results(10) on spontaneous heating and spontaneous ignition in fibre insulating board, and that this descrepancy suggests that the reaction model is inadequate. Again, the observation in the present work that the 3 mm layers of dust could not be ignited on a surface heated from room temperature, but only when deposited on a preheated surface, indicates the presence of a rate process not included in the simple theory; although this effect disappears in the thicker layers.

For the present, however, Fig.5. is regarded as a useful practical guide with a not unreasonable theoretical foundation.

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CONCLUSIONS

Studies of the ignition of layers of beech sawdust on a hot surface confirm the results of other workers that the depth of the layer is the most important factor affecting the minimum temperature of the hot surface for ignition.

The experimental results have been adequately correlated by a thermal theory of ignition based on the simple model of a first order exothermic reaction, in which loss of reactant may be neglected and which obeys the Arrhenius law, in a slab with one face at a constant high temperature and the other cooling to the surroundings.

Application of the theory to the results for a given material yield two reaction constants; E, the activation energy and QF, the product of the heat of reaction per gram and the pre-exponential factor of the Arrhenius equation. Once they have been determined, critical depths and temperatures for ignition may be predicted.

Although the simple reaction-model appears to be adequate for the ranges within which the variables have been examined, it does not follow that the reactions responsible for ignition are so simple or that E and QF have any absolute significance. There is, in fact, an indication that the ignition process is more complex than has been assumed.

The theory predicts that the density of the layer will affect the ignition temperature in thin layers only, and this appears to be borne out by the results.

For sieve fractions in the range 18-120 B.S. ignition was independent of particle size. The sieve fraction passing 120 B.S. ignited at significantly lower temperatures - at least in the thinner layers - than the coarser fractions at given depths.

the coarser fractions at given depths.

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APPENDIX I

Thermal conductivity of beech sawdust

A tabulated value[13] for the thermal conductivity of sawdust described as "various" and of unspecified moisture content, is 1.4×10^{-4} cal cm^{-2} s^{-1} ($^{\circ}C$ cm^{-1})$^{-1}$ at a density of 0.2 g cm^{-3}. Since, for the present purpose, a value that can be regarded as more likely to be representative of dry beech sawdust is desirable, and it is also necessary to estimate the effect of changing density on the thermal conductivity, an attempt has been made to calculate the conductivity of the sawdust from the bulk properties of beech wood.

An equation due to Maxwell[14] expresses the thermal conductivity, Ka, of a porous or granular material as

$$K_a = K_s. \frac{1 - (1 - aK_p/K_s) \cdot b}{1 + (a - 1) b} \qquad \dots\dots\dots(3)$$

where,

$a = 3 K_s/(2K_s + K_p)$,

$b = V_p/(V_s + V_p)$,

$V_s =$ volume of continuous phase,

$V_p =$ volume of discontinuous phase,

$K_s =$ thermal conductivity of continuous phase,

$K_p =$ thermal conductivity of discontinuous phase.

The equation was derived from small values of b, but according to Eucken[15] it is valid for b up to 0.5. According to de Vries[16] the accuracy of the equation depends also on the ratio of the conductivities of the continuous and discontinuous phases.

For a granular material, such as sawdust, where the mass of air in a given volume is small compared with the mass of the solid, it can be shown that

$$b \approx \frac{\rho_a}{\rho_p}$$

where,

$\rho_a =$ bulk density of material

$\rho_p =$ density of particles.

For dry beech of density 0.70, MacLean's formula relating thermal conductivity to density[17] yields $K = 3.93 \times 10^{-4}$ c.g.s. units for conduction across the grain. The tabulated value[18] is 4.00×10^{-4} but, since the moisture content to which this value corresponds is not stated, the former value is used below.

MacLean's results[17] on Douglas Fir and Red Oak of moisture content ranging from 6 to 15 per cent showed that thermal conductivity parallel to the grain was $2\frac{1}{4}$ to $2\frac{3}{4}$ times the conductivity across the grain. Taking a mean value of $2\frac{1}{2}$ for this factor, the thermal conductivity for beech parallel to the grain is estimated as 9.8×10^{-4} c.g.s units.

For randomly orientated particles of beech sawdust we use a conductivity equal to $\frac{1}{3}$(2K across +K along), i.e. 5.9 x 10-4. Taking the conductivity of air as 0.586 x 10-4 and inserting these values in equation (3) we have

$$K_a = 0.586 \frac{1 + 1.56\ b}{1 - 0.78\ b} \times 10^{-4} \text{ c.g.s. units.}$$

The following values for K_a are of interest in this note:-

a	b	K_a	
0.26	0.36	1.27 x 10-4	c.g.s. units
0.28	0.40	1.35 x 10-4	"
0.37	0.53	1.76 x 10-4	"
0.44	0.63	2.16 x 10-4	"

de Vries's conclusions(16) indicate that for the higher densities, the calculated thermal conductivities may be too low by 10-25%.

APPENDIX II

Details of calculation of activation energy etc.

1. Calculation of

The sawdust is assumed to be inert so that the heat flux at the cool surface is given by the simple conduction equation. With this assumption the cool surface temperature is determined by graphical solution of the following equation for the thermal balance at the cool surface:-

$$\frac{K(t_p - t_s)}{2 r} = \sigma\left[(t_s + 273)^4 - (t_o + 273)^4\right] + h_c(t_s - t_o) \quad \ldots\ldots(4)$$

where

t_p, t_s, t_o = temperatures of hot surface, cool surface, and surroundings respectively, °C.

σ = Stefan-Boltzmann constant, c.g.s. units.

h_c = convective heat transfer coefficient.

The temperature of the surroundings was taken as 25°C.

For temperatures of the cool surfaces of the dust layers estimated initially on the assumption of turbulent convection, the product of the Prandtl and Grashof Numbers was between 6×10^5 and 6×10^6. The following expression for the heat transfer coefficient for streamline convection, was therefore used[19]:-

$$h_c = 9.86 \times 10^{-5} \frac{(t_s - t_o)^{1.25}}{L^{0.25}} \text{ cal cm}^{-2} \text{ sec}^{-1} \text{ °C}^{-1}$$

The characteristic length L was taken as $r\sqrt{\pi}$ where r was the radius of the dust layers.

Since the dust layers did not cover the whole surface of the hot plate they were surrounded by an annulus at a temperature higher than that of the dust layers. Convective heat loss from the dust layers is therefore probably overestimated by the above expression and surface temperatures correspondingly too low.

α is given by

$$\alpha = \frac{t_p - t_s}{2(t_s - t_o)}$$

3. Activation energy

We have

$$E = 2.303 \ R \ \frac{\log_{10}\left(\frac{\sigma c\ T_p^2}{r^2}\right)_1 - \log_{10}\left(\frac{\sigma c\ T_p^2}{r^2}\right)_2}{(1/T_p)_2 - (1/T_p)_1}$$

where the subscripts 1 and 2 refer to two points on the line

$$\log_{10} (\delta_0 T^2/r^2) \text{vs. } 1/T$$

It is necessary, first, to assume a value of E in order to calculate θ_0 and so obtain δ_c from Fig.1. The value of E calculated from the above equation is then used to correct θ_0 and δ_c. Further approximations may be made if desired, but they will usually be unnecessary since δ_c appears in the logarithms and E is therefore relatively insensitive to systematic errors in δ_c.
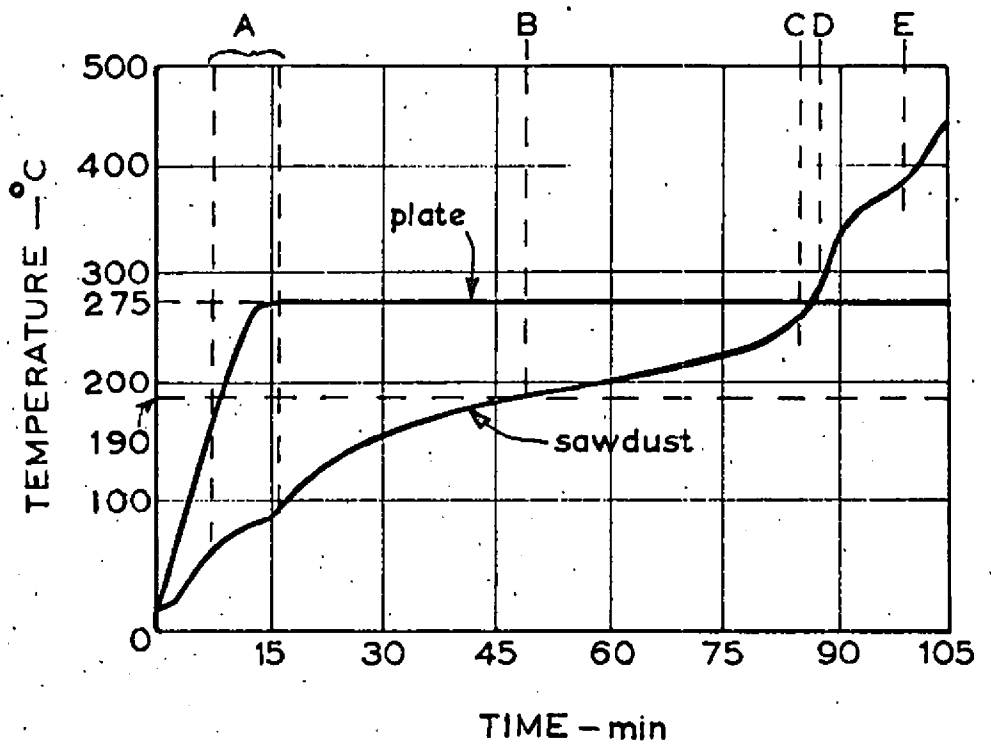
FIG.I. IGNITION OF 2·5 cm LAYER OF BEECH SAWDUST ON SURFACE AT 275°C
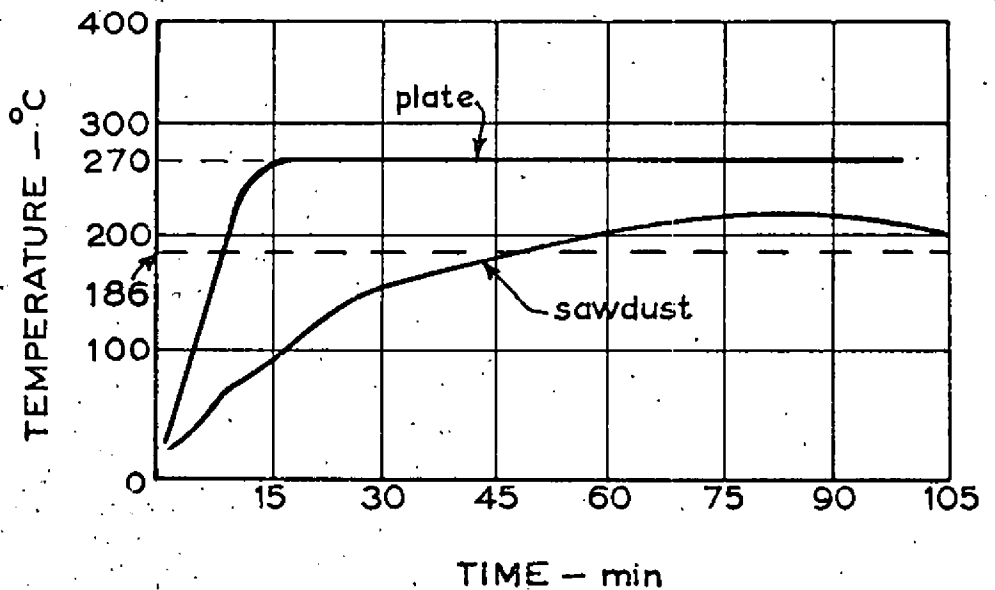
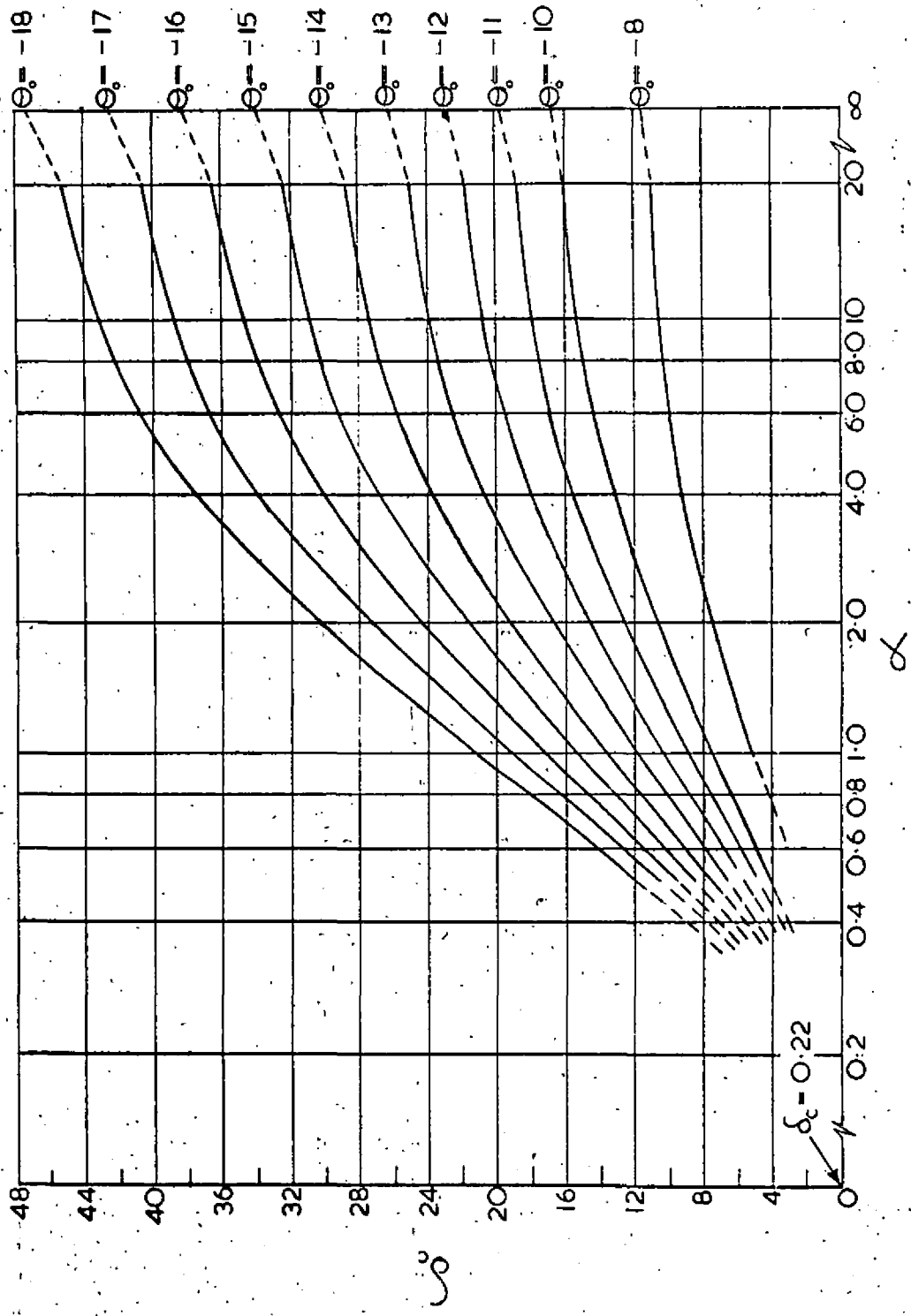FIG.2. SELF HEATING IN 2·5 cm LAYER OF BEECH SAWDUST ON SURFACE AT 270 °C

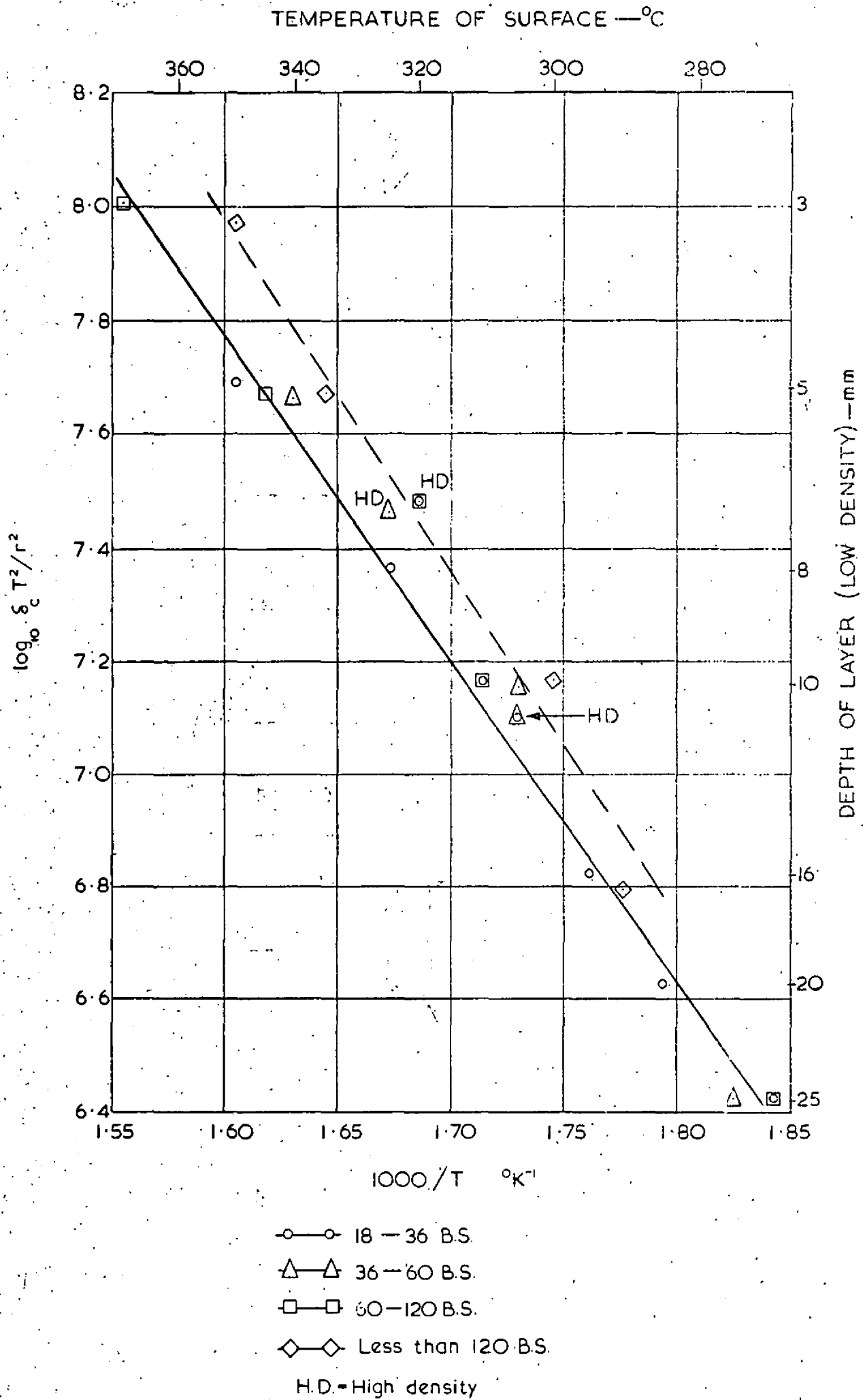FIG. 3. δ_c AS A FUNCTION OF α AND θ_o

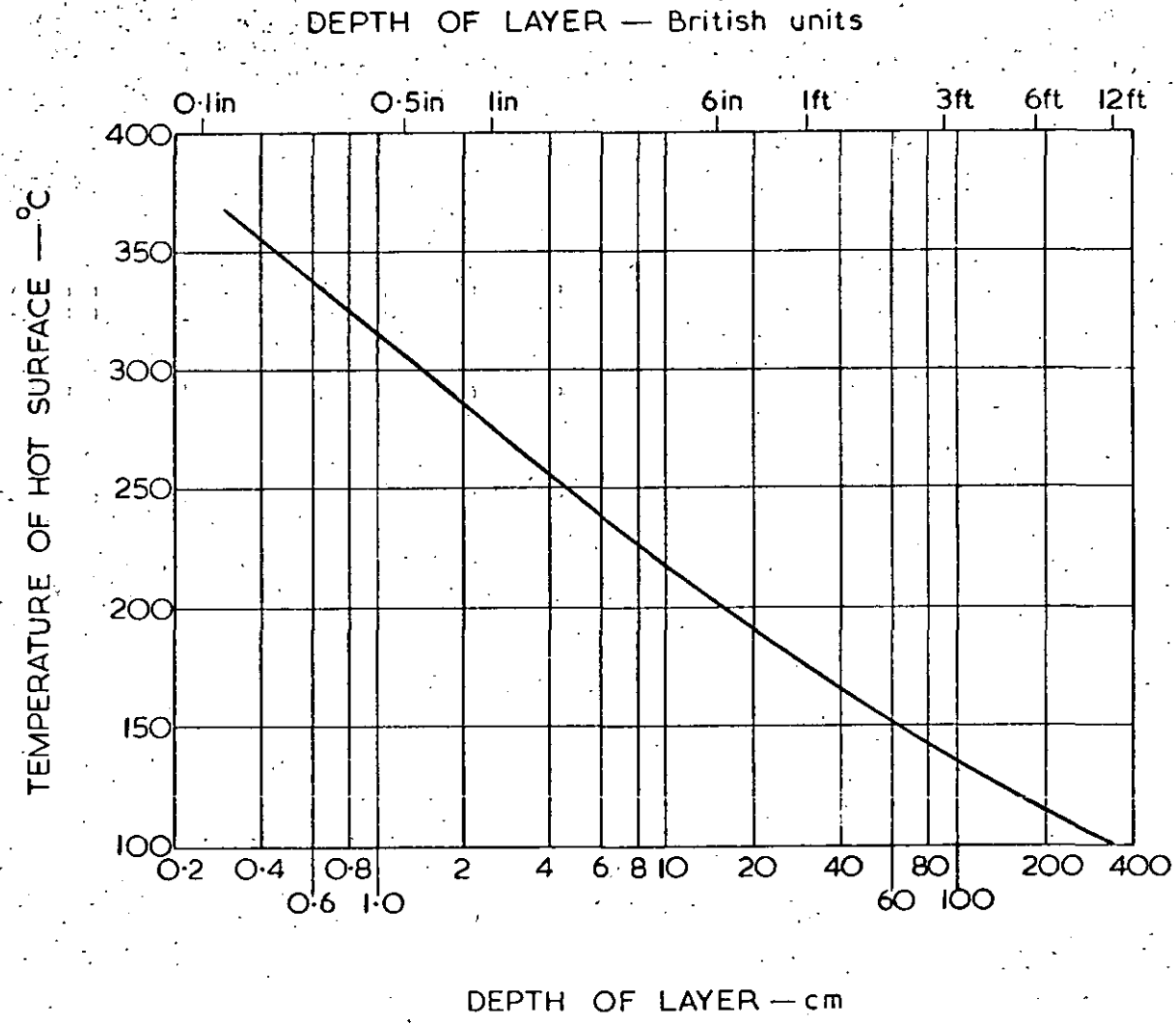FIG. 4. IGNITION OF BEECH SAWDUST LAYERS ON HOT SURFACE

FIG. 5. IGNITION OF LAYERS OF BEECH SAWDUST ON HORIZONTAL HOT SURFACE.
PREDICTED RELATIONSHIP FOR SURROUNDINGS AT 25 °C