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SMOULDERING IN DUSTS AND FIBROUS MATERIALS.

Part II. Powdered Cocoa, Grass and Cork in still air

by

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Summary

The smouldering of powdered cocoa, grass and cork has been investigated; these powders are industrial hazards because of their liability to produce dust explosions. The dusts were formed into small trains; smouldering was then initiated and its linear rate of propagation measured. The minimum depths of train necessary to sustain smouldering were also determined, in some cases they were very small (2-3 mm). Experiments with trains of cork dust supported upon metal or asbestos showed that the burning time of the dust was not measurably affected by the thermal conductivity of the supporting base.

Smouldering in all the dusts was initiated easily by a cigarette end.

1. Introduction

This note describes further work upon the properties of smouldering in various combustibles; previous experiments upon beech and deal sawdusts have already been described.(1) It was found in these earlier experiments, which were carried out in still air, that no appreciable effect was produced upon the rate of propagation of smouldering in trains of sawdust by changes in packing density, moisture content, particle size and size of train, provided that the train depth was greater than a certain critical value depending chiefly upon the particle size. If the train depth were less than this critical value no sustained smouldering occurred.

The work has been extended to include the investigation of certain industrial dusts which represents a common industrial hazard, because of their liability to produce dust explosions; the main purpose being the determination of the rates at which smouldering is propagated, if at all, and the minimum depths of layer or train necessary for its sustenance. Such information would be of value in both the investigation of fires in buildings etc. where these dusts could accumulate and in the consideration of the development of dust explosions. It is possible, in some cases, that the production of smouldering is an intermediate stage between ignition of the dust and the propagation of an explosion.

2. Experimental

Samples of six hazardous dusts were obtained from the Safety in Mines Research Establishment, Buxton, and preliminary tests showed that three dusts would not support sustained smouldering, these were: aluminium stearate, a phenol-formaldehyde resin and starch. The aluminium stearate and the resin melted to clear liquids, the starch charred but also partially liquefied. Experiments were therefore restricted to the three remaining dusts (cocoa, grass and cork) and they were carried out in still air at room temperature.

The rates of smouldering of the cocoa, grass and cork were measured upon the unsieved dusts and additional experiments upon a range of sieve fractions of the cork dust were also carried out. The moisture contents of the dusts were determined as before (1) and are given in Tables 1 and 2. No experiments were carried out upon oven dried dusts and the packing densities given below are calculated for the dusts as received.

Table 1

Moisture contents of unsieved dusts

Dust	Moisture content %
Cocoa	6.0
Grass	8.1
Cork	7.2

Table 2

Moisture contents of sieve fractions of cork dust

Sieve fraction B.S.	Mean particle diameter cm.	Moisture content %
25 - 60	0.0424	5.6
60 - 72	0.0231	6.4
72 -120	0.0168	7.5
120 -240	0.0095	7.5
thro' 240	$<$ 0.0066	7.8

The apparatus and experimental procedure used in the determinations of the burning times of the unsieved dusts were the same as those used for sawdust(1); trains of the dust were formed from a series of moulds (A-F, see Table 3) upon a previously dried asbestos millboard base, smouldering was then initiated by a small gas flame and the mean time of travel per cm. was taken as the "burning time". The minimum depths of layer necessary for sustained smouldering in the three unsieved dusts, were also determined as before by using the wedge-shaped moulds (Y and Z).

The effect of variation in the thermal conductivity of the material upon which the trains rested was also investigated: trains of various sieve fractions of the cork dust were supported either upon asbestos millboard or upon a large metal block and the burning times measured. The metal block consisted of several iron slabs covered by a duralumin sheet. Additional experiments using the metal base-plate were performed with trains formed from the smaller wedge mould (Y).

All experiments were carried out in a draught-free fume cupboard.

3. Results

The smouldering observed in trains formed from cocoa, grass or cork was similar to that obtained with wood sawdust; thus the trains which sustained smouldering propagated combustion steadily and the division between the burnt and unburnt parts of the trains was distinct and easily visible. All the dusts formed trains which could be ignited by a glowing cigarette-end.

Cocoa

Smouldering was propagated in powdered cocoa at an even, but very slow, rate; the measurements made of the burning times (min/cm) are given in Table 3. The minimum depth of a layer of the dust necessary for sustained smouldering to occur was also investigated and the result is given in Table 4.

The smouldering of cocoa was accompanied by the evolution of a dense white smoke which could be momentarily ignited by a small gas flame; however, attempts to propagate flame in a small closed vessel containing the smoke were unsuccessful, possibly because of the condensation of smoke upon the walls. It was also noticed that the carbonised residue remaining after the propagation of smouldering broke up vertically into irregular hexagonal columns, separated by gaps of 1-2 mm, whereas the wood sawdust had produced a friable carbonised mass.

Table 3

The burning times (min/cm) of trains of unsieved cocoa, grass and cork resting upon asbestos millboard

Mould		A	B	C	D	E	F
Vertical depth along centre of mould cm		0.30	0.80	1.00	1.65	2.40	3.70
Burning Time (min/cm)	Cocoa	n.s.	n.s.	n.s.*	18.9	17.8	-
	Grass	2.4	2.2	2.5	4.2	5.2	-
	Cork	n.s.	2.4	2.7	2.6	3.2	2.9

Packing densities: Cocoa: 0.50 gm/ml Grass: 0.28 gm/ml Cork: 0.10gm/ml

Notes: n.s. = "sustained smouldering not supported" - = "not determined"

* Combustion zone wandered to side of train and extinguished.

Grass

Measurements of the burning times of trains of grass dust are given in Table 3 and the minimum depth of train necessary for sustained smouldering is shown in Table 4. The smouldering trains of grass gave smoke and ash similar in appearance to those formed from wood sawdust.

Table 4

The minimum depths of layer necessary for sustained smouldering in various dusts.

Dust	Packing density gm/ml	Base	Minimum depth for smouldering cm.
Cocoa	0.46	Asbestos	0.9
Grass	0.28	"	$<$ 0.2
Unsieved cork	0.10	"	0.5
Sieved cork: 25-60 B.S.	0.10	"	0.7
" " "	0.10	Metal	0.8
thro240B.S.	0.13	Asbestos	0.3
" "	0.13	Metal	0.3

Unsieved cork

The experiments with unsieved cork were similar to those upon cocoa and grass dusts; details of the results are given in Tables 3 and 4. The appearance of the smoke and ash was again similar to those from wood sawdust.

Sieved cork

The burning times of the trains formed from the various sieved fractions of cork dust are shown in Table 5; results were obtained from trains resting upon either asbestos millboard or metal. The minimum depths of train necessary for the sustained smouldering of two sieve fractions of cork dust are shown in Table 4; determinations were made with trains resting upon both types of base.

The wandering of the combustion zone in trains which sustained smouldering with difficulty was investigated in more detail after the zone in a train of the 25-60 B.S. sieve fraction had extinguished itself at the side of the train. A layer of the dust was formed evenly, to a depth of 1.0 cm, over the metal base block; the top sheet of metal and the dust layer, after smouldering was completed, are shown in Plate 1 (left). The critical depth for sustained smouldering in a layer of this dust was shown earlier to be 0.8 cm. (Table 4). Smouldering was initiated at the centre of the side nearest the centimetre scale, the combustion zone immediately divided and the left-hand portion eventually travelled the whole length of the layer, with further divisions at several points, before returning along the left-hand side. A similar experiment with a layer 1.9 cm in depth is shown in Plate 1 (right) but in this case, after ignition, the combustion zone spread uniformly across the layer and persisted until most of the dust was completely carbonised.

The burning time of the cork dust in the shallower layer was approximately equal to that for more uniform propagation in deeper trains; however, as wandering of the combustion zone occurred, the time for which smouldering persisted in a given length of the shallower layer was greater than in the deeper layer.

Table 5

Burning times (min/cm) of trains of sieved cork resting upon an asbestos or metal base

Sieve fraction B.S.	Packing density gm/ml	Trains from mould: A		B		C		D	
		Asbestos	Metal	Asbestos	Metal	Asbestos	Metal	Asbestos	Metal
25 - 60	0·10	-	-	2·0	n.s	3·6	n.s*	2·9	3·0
60 - 72	0·10	-	-	-	-	2·6	2·7	-	-
72 - 120	0·10	2·4	2·4	2·1	2·1	-	-	-	-
120 - 240	0·10	2·0	1·8	2·1	2·1	-	-	-	-
thro' 240	0·13	2·4	2·8	2·0	-	2·2	-	-	-

4. Discussion

The burning times of powdered cocoa, grass and cork, given in Tables 3 and 5 are of the same order as those obtained with beech and deal sawdust (1). The finest fractions of these latter dusts gave values for the burning time of 8 - 10 min/cm and 4 - 7 min/cm respectively; thus all fractions of cork dust smouldered at slightly faster rates than the wood dusts (2 - 4 min/cm) whereas the smouldering of cocoa was considerably slower (18 min/cm). In general, however, the properties of smouldering in cocoa, grass and cork were similar to those in wood dusts; thus variation in size of train, or in particle size of the sieved cork, produced no appreciable effect upon the burning times. Smouldering in larger trains of grass dust appeared to be somewhat slower than in the smaller trains (Table 3), but this effect was not investigated in more detail. The substitution of metal for asbestos as the material upon which the trains rested produced no detectable effect upon the burning times of fractions of sieved cork (Table 5). As duralumin and asbestos have widely differing thermal conductivities (0·3 and 0·3 x 10^{-3} cal/cm/sec/°C respectively), and as no effect upon the smouldering was observed, it is probable that the burning time of a layer of cork dust upon any metal girder will not differ greatly from that of a similar layer upon a wooden beam.

A further point of resemblance between the smouldering of cocoa, grass and cork, and that of wood sawdust is the existence of critical depths of layers of dust necessary for sustained smouldering to occur. The values for the different dusts, given in Table 4, are in some cases remarkably low; however, they are consistent with the results given in Tables 3 and 5. The critical depth of powdered grass was less than 0·2 cm and that of the finest cork dust was only 0·3 cm; it thus follows that even a thin deposit of these dusts presents a smouldering fire hazard. There is some indication in Tables 4 and 5 of the critical depth increasing with the thermal conductivity of the base upon which the dust layer rests; but the effect was only slight and it was not investigated further.

Smouldering in layers of dust slightly deeper than the critical value may continue for longer periods than in layers of greater depth. This is a consequence of the combustion zone not extending laterally in the shallow layers, but remaining a narrow band, and wandering at random throughout the layer; the distance travelled by the combustion zone thus may be greater than in deeper layers in which smouldering extends more widely. As the burning time is approximately independent of the depth of the train, smouldering in shallow layers may therefore outlast that in deeper layers which are otherwise similar.

It is noteworthy that smouldering was easily initiated in all three dusts by a glowing cigarette-end; the possibility of producing smouldering with other weak sources, such as friction sparks, needs further investigation; it is important because it may be a direct cause of some dust explosions. Future work upon the variation of burning time with draught, and the transition from glowing to flaming in these dusts, is also planned.

5. Conclusions

1. Cocoa, grass and cork dusts, formed into trains, will undergo sustained smouldering in a similar manner to wood sawdust. Experiments with a range of sieve fractions of cork dust showed that the rate of smouldering was not materially affected by variations in particle size or the thermal conductivity of the base upon which the trains rested.

2. If smouldering is to be sustained, the dust layer must be deeper than a certain critical value. With some dusts this minimum depth is small (2 - 3 mm).

3. Smouldering in the three dusts was easily initiated by a glowing cigarette-end.

Acknowledgement

The supply of dusts was arranged by Mr. K. C. Brown, H.M. Inspector of Factories, Safety in Mines Research Establishment, Harpur Hill, Buxton.

References

1. F.R. Note No. 6/1952.

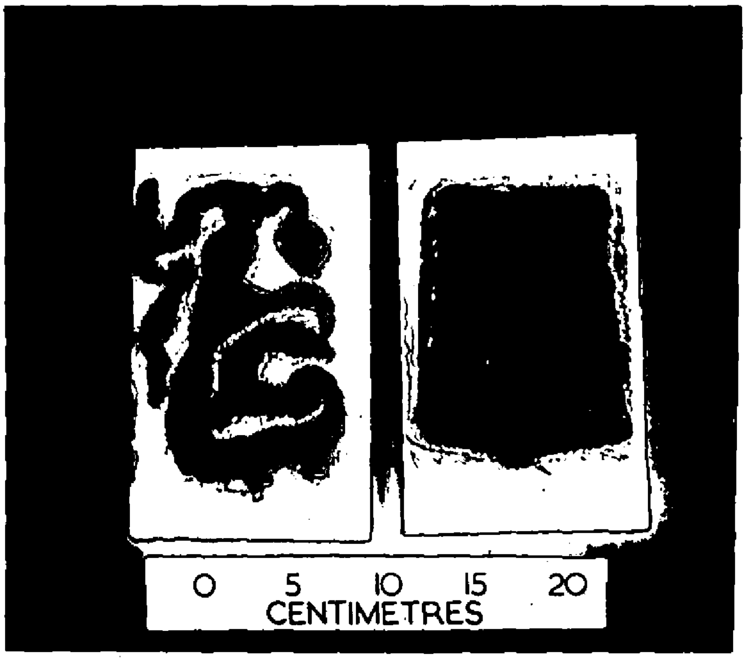

PLATE 1 SMOULDERING IN LAYER OF 25-60 B.S. CORK DUST