Fire Research Note
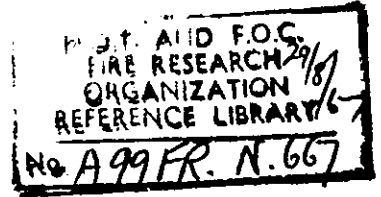
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EFFECT OF DILUENT DUSTS ON THE EXPLOSIBILITY
OF SOME PLASTICS DUSTS

by

K. N. PALMER and P. S. TONKIN

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SUMMARY

The proportions of barium sulphate and magnesium oxide dusts required to prevent explosions in phenol formaldehyde resin and polyethylene dusts dispersed in air in a large scale vertical tube have been determined. The behaviour of the dust mixtures in the routine small scale Classification tests has also been studied. In further experiments with small scale apparatus, the explosibility of mixtures of phenol formaldehyde resin with other diluents has been observed.

The results have been used to test further a theory developed previously for determining the percentage of diluent required to prevent explosion when dispersed with the combustible dust. The theory was based on a heat balance in which the function of the diluent dust was to act solely as a heat sink. The theory was in good agreement with the results obtained with the large scale apparatus, and with most of the results from the small scale apparatus. A diluent which was markedly more effective than predicted was sodium iodide.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

Previous work[1, 2, 3] with dusts and dust mixtures dispersed in air
enabled a comparison to be made between the explosibility of the dusts in
a large scale vertical tube of industrial proportions and the explosibility
Classifications as determined in small scale test apparatus. The dust
mixtures were made from phenol formaldehyde resin, a readily explosible dust
(Class I), and from magnesium oxide, a non-explosible dust (Class III).
As the proportion of magnesium oxide was increased, the range of explosible
concentrations of the mixtures in the vertical tube decreased until,
eventually, propagation of flame did not occur at any concentration of the
mixture. The behaviour of this mixture in the small scale tests was then
observed.

By considering the thermal properties of the magnesium oxide and the
phenol formaldehyde resin, and by assuming that the magnesium oxide acted
as a heat sink, a calculation was made of the minimum amount of diluent
dust required to prevent explosions in the phenol formaldehyde resin. The
calculated value was in good agreement with that found experimentally[2].

In order to obtain a further check of the validity of the theory,
further work has been carried out with the large scale vertical tube
apparatus. Firstly, the magnesium oxide was replaced with barium sulphate,
which is also thermally stable but has a different specific heat.
Secondly, the phenol formaldehyde resin was replaced by polyethylene dust,
which has a different heat of combustion, and which was then mixed with
magnesium oxide. Both types of mixture were also tested in small scale
Classification tests.

Some additional tests, described in the Appendix, were carried out in small scale apparatus with the phenol formaldehyde resin mixed with a number of other diluent dusts. These tests provided further information on the behaviour of various diluents, conveniently and economically.

Experiments involving the explosion of dusts mixed with diluents, lead to a better understanding of the mechanism of propagation of dust explosion flames. They are also of practical importance, because frequently in industry combustible dusts become mixed with non-combustible material, and an understanding of how the explosibility of the mixture is altered can lead to the specification of more economic safety measures.

EXPERIMENTAL

Materials

The dusts used in the large scale vertical tube were phenol formaldehyde resin (Class I), polyethylene (Class I) magnesium oxide (Class III) and barium sulphate (Class III).

The phenol formaldehyde and magnesium oxide dusts were industrial grade powders with mean particle diameters of 15 and 11 microns respectively. The barium sulphate was a precipitated commercial powder of mean particle diameter 6 microns; the polyethylene was a commercial powder with a sizing analysis given in Table 1. The moisture contents of the dusts are listed in Table 2.

Table 1

Sizing analysis of polyethylene

B.S. Mesh	Per cent by weight
- 60 + 72	20.2
- 72 + 120	62.5
-120 + 240	16.5
-240	0.5

Table 2

Moisture contents of the dusts

Dust	Moisture content, per cent by weight
Phenol formaldehyde resin	4.1
Polyethylene	nil
Magnesium oxide	2.2
Barium sulphate	0.1

The dust mixtures were made in a rotating drum mixer and checked as previously[2]. The time required for effective mixing was 1 hour with polyethylene, and 2 hours with phenol formaldehyde.

Apparatus

The vertical explosion tube was the same as that described previously[2], and is shown in Fig. 1. The internal diameter of the tube was 25.4 cm and its overall length was 5.2 m. It was provided with perspex windows and sections for flame photography, and could be used with either the top open and the bottom closed or with the top closed and bottom open. The igniting source was again a propane air flame injected into the tube 3.7 m from the top. The dust was fed steadily into the top of the tube, as previously, and allowed to fall under gravity.

Procedure

The experimental methods have been described in detail elsewhere[2]. Briefly, a steady concentration of the dust mixture was established and measured, and three explosion tests were carried out. Observation was made as to whether or not flame propagated into the dust cloud. The dust concentration was then determined again. The tests were repeated with different concentrations and with different dust mixtures. The measurement of dust concentration and distribution across the diameter of the tube were carried out as previously.

Results

Measurement of flammability limits

The flammability limits of phenol formaldehyde resin-barium sulphate and polyethylene-magnesium oxide mixtures are shown in Figs 2 and 3; the percentages of diluent dust have been plotted on broken axes against the total dust concentration. Figures 2 and 3 show the range of explosibility for each dust mixture, distinction being made between the flame propagation over the whole length of the tube, propagation over part of the tube length (i.e. propagation more than 0.6 m but not over the whole tube length), and no flame propagation. Each point represents a group of three tests and shows the greatest extent of flame propagation within the group. For all these tests the top of the tube was open, and the bottom was closed, with ignition near the lower end.

The lower explosibility limit of polyethylene dust alone was also measured and the results are given in Table 3. They were obtained with the top of the tube closed and the bottom open, with ignition near the open end. Other results obtained with ignition near the closed end are shown in Fig. 3. Under both sets of conditions the concentrations were low, and the dust clouds were almost transparent.

Table 3

Lower explosibility limit of polyethylene dust;
ignition near open end of tube

Dust concentration g/l	Extent of flame propagation
0.008	None
0.011 0.017 0.019 0.021	Part tube length " " " " " " " " "
0.024 0.034 0.041 0.046	Whole tube length " " " " " " " " "

Each of the dust mixtures, as well as the two combustible dusts, were classified for explosibility in the small scale apparatus described previously[1]. Table 4 gives a summary of the results of these tests.

Table 4

Results of explosibility tests in small scale apparatus

Mixture composition		Explosibility Class	Test apparatus in which ignition occurred	Minimum ignition Temperature $^\circ C$		Minimum explosible concentration g/l	Maximum explosion pressure		Maximum rate of pressure rise	
Fuel per cent wt	Diluent per cent wt			Apparatus (a)	Apparatus (e)		lbf/in^2	kgf/cm^2	$lbf/in^2/s$	$kgf/cm^2/s$
100 Phenol-formaldehyde resin	Nil	I	a - e	1000	450	0.015	107	7.5	6,500	455
15 "	85 Barium Sulphate	I	b - e	-	520	-	-	-	-	-
10 "	90 "	II	e	-	520	-	-	-	-	-
5 "	95 "	II	e	-	600	-	-	-	-	-
100 Poly-ethylene	Nil	I	a - e	960	420	0.006	66	4.6	600	42
20 "	80 Magnesium oxide	I	b, d, e	-	630	-	-	-	-	-
15 "	85 "	I	b, d, e	-	630	-	-	-	-	-
10 "	90 "	I	d, e	-	650	-	-	-	-	-
5 "	95 "	I	d, e	-	700	-	-	-	-	-

Apparatus a: Horizontal tube
b: Inflammator
c: Hartmann
d: Modified Hartmann
e: Furnace

The distribution of dust in the explosion tube along one diameter is shown in Fig. 4, for one dust mixture. Similar distributions were obtained with each dust mixture used in the tube, when the top of the tube was open and the bottom closed.

The variation of the mean velocity of fall of the dusts with concentration is shown in Fig. 5. Similar curves were obtained for each dust mixture. The mean velocity of fall of polyethylene dust alone was measured at a concentration of 0.01 g/l, which was near the lower explosible limit, and was 40 cm/s. The corresponding values for phenol formaldehyde resin, reported previously[2], were 0.03 g/l and 50 cm/s.

Flame velocities

The velocities of the flames propagating in thin dust clouds of polyethylene and in marginally explosible polyethylene-magnesium oxide mixtures are given in Table 5. The flames in marginally explosible phenol formaldehyde resin-barium sulphate mixtures were fragmented and not sufficiently luminous for clear photography and hence the flame velocities could not be accurately measured.

Table 5

Flame velocities in weak explosions

Dust Mixture	Tube arrangement	Concentration Range g/l	Flame velocities	
			Minimum cm/s.	Maximum cm/s.
Polyethylene alone	Top closed bottom open	0.012 - 0.020	90	160
Polyethylene alone	Top open bottom closed	0.030	160	350
Polyethylene-Magnesium oxide (20 : 80)	"	0.15 - 0.68	360	450

DISCUSSION

Flammability limits determinations

Lower and upper flammability limits were obtained with two explosible
mixtures of phenol formaldehyde resin and barium sulphate and with three
mixtures of polyethylene and magnesium oxide. The minimum percentage of
the diluents required to prevent explosions in the large scale apparatus
were also determined. As in previous work[2] the flames were of three types:
those that propagated the whole length of the tube, those that propagated
over part of the tube, and flames that did not propagate away from the source
of ignition. An explanation of the existence of partial propagation is that
as the flame was propagating relatively slowly, and its composition was near
the flammability limits, it was readily affected by random variations of con-
centration in the dust suspension. Dust mixtures that were only able to
sustain partial propagation have therefore been regarded as explosible for
practical purposes.

The curves in Figures 2 and 3 were similar in shape and characteristics
to those obtained previously[2]. The dust concentration shown are those
measured in the experiments (static mass concentration) but because the dust
was falling through the air in the tube the quantity entering the flame was
greater than if the dust had been stationary. By allowing for the dust move-
ment, the kinetic mass concentrations were calculated as previously[2], and are
shown in Figures 6 and 7 for concentrations near the flammability limits.
For the calculation the mean velocities of fall of the dust mixtures were
required, Fig. 5, and the flame valocities at the flammability limits were
assumed to be those measured on the fuels alone. This assumption is justified
on the grounds that the effect of the diluent was taken to be that of a heat
sink, see below, and the limiting condition for propagation was that the flame
temperature was reduced to that at the lower flammability limit for the fuel
alone. The correction to a basis of kinetic mass concentration does not
of course, affect the minimum percentage of diluent required to prevent
explosion.

The dust concentration at the lower flammability limit of polyethylene
in air was very low (Figs 3 and 7, and Table 3). At such low concentrations
the dust clouds were very thin and were not easily observed in the explosion
tube. The traditional rule of thumb which states that for a dust cloud to

be explosible the visibility would not exceed 50 - 100 cm, cannot be safely applied to polyethylene clouds in air. The rule probably originated with coal dust suspensions, but clearly it cannot be applied without reservations to industrial dusts generally.

Comparison between large scale and Classification test results

With phenol formaldehyde resin-barium sulphate mixtures explosions were obtained in the large scale vertical tube with fuel/diluent mixtures 15/85 and 10/90 but not with the 5/95 mixture. In the small scale tests only the 15/85 mixture was classified as a Class I dust. The 10/90 mixture was placed in explosibility Class II. The ability of the 10/90 mixture to propagate flame in the large scale apparatus was anomalous, because all previous Class II dusts and dust mixtures failed to propagate in the large scale tube. With the 10/90 mixture the dark red flames obtained were small and propagated for short distances only, the maximum distance being about 1.2 m from the igniting position. The criterion for partial propagation is that the flame should travel at least 0.6 m from the igniting position and hence the mixture was clearly very near to the dividing line between explosibility Classes I and II. Because of the very limited extent of propagation, and the general feebleness of the flame, explosion pressure damage with this mixture would not be likely. Further evidence of the dividing line between Class I and Class II mixtures has been obtained theoretically, see below.

With polyethylene-magnesium oxide mixtures, explosions were obtained in the large scale apparatus with mixtures containing 90 per cent or less of magnesium oxide. In the small scale tests, Table 4, all these mixtures were Class I, as also was the 5/95 mixture. The small scale test thus slightly overestimated the explosibility of the mixtures, although the theoretical considerations given below indicate that the dividing line between Class I and Class II would be near the 5/95 mixture.

Theoretical consideration of flame quenching

In the work reported earlier on phenol formaldehyde resin - magnesium oxide mixtures[2] an estimate was calculated of the percentage of magnesium oxide required to prevent explosion of the resin dust. By assuming that the magnesium oxide was chemically inert, and that it acted only as a thermal sink, equations were derived relating the combustion properties of the resin

to the thermal properties of the magnesium oxide. The assumption was that if the flame temperature were reduced by cooling to a value less than that of the flame at the lower flammability limit of fuel, then the flame would be quenched. The lower and upper flammability limits of resin-magnesium oxide mixtures could then be calculated, and as the proportion of magnesium oxide was increased the flammability limits converged. Eventually, when the fuel concentration was stoichiometric the two limits coincided; this mixture was such that it could only propagate flame at one concentration in air, and was termed the 'peak value'. Mixtures containing a higher percentage of magnesium oxide than the peak value would not propagate flame at any concentration when dispersed in air at room temperature.

The equation for dust concentrations between the lower flammability limit and stoichiometric, stoichiometric and the upper flammability limit, and the peak value, were respectively

$$y = \frac{H (x - x_1)}{rc_2 (T_1 - T_o)} \tag{1}$$

$$y = \frac{H (x_2 - x_1)}{rc_2 (T_1 - T_o)} - \frac{c_1}{rc_2} (x - x_2) \tag{2}$$

$$y = \frac{H (x_2 - x_1)}{rc_2 (T_1 - T_o)} \tag{3}$$

where x is resin concentration (mass per unit volume)

x_1 is resin concentration at lower flammability limit

x_2 is stoichiometric concentration

y is concentration of diluent dust (mass per unit volume)

c_1 is mean specific heat of resin vapour, neglecting heat of vaporisation

c_2 is mean specific heat of diluent dust

T_1 is flame temperature at flammability limits

T_o is ambient temperature

H is heat of combustion per unit mass of resin

r is expansion ratio on combustion

For phenol formaldehyde resin the following values were taken[2].

$x_1 = 0.045$ g/l

$x_2 = 0.12$ g/l

$c_1 = 0.35$

$T_1 = 1370°K$

$T_0 = 300°K$

$H = 8000$ cal/g

$r = T_1/T_0 = 4.6$

In the present work the phenol formaldehyde resin was used with barium sulphate as the diluent, the specific heat (c_2) of which was 0.14[4].

With polyethylene the chemical composition was taken as $(CH_2)_n$ and hence the stoichiometric concentration in air (x_2) was 0.088 g/l. The lower explosibility limit determined experimentally (Table 3) was 0.010 g/l, but because at this concentration the dust was falling at 40 cm/s and the upward velocity of the flame was 90 cm/s (Table 5), the concentration of dust in the flame was $0.010 \times \frac{130}{90}$. That is, $x_1 = 0.015$ g/l approximately. The specific heat of polyethylene (c_1) was taken as 0.53 for both solid and vapour phases[5]. The heat of combustion (H) was calculated[4] as 10500 cal/g and hence the flame temperature at the lower limit (T_1) was 790°K[6]; $r = T_1/T_0 = 2.6$. The specific heat of magnesium oxide (c_2) was 0.28[2].

The above values for the phenol formaldehyde and polyethylene systems were substituted in equations 1 and 2, and the lines obtained are shown in Fig. 6 and 7. Agreement between the calculated lines and the experimental results was better for the polyethylene - magnesium oxide mixtures than for the phenol formaldehyde - barium sulphate system. In the latter case, near the peak value, the flammability limits were considerably wider than calculated. For both the polyethylene and the phenol formaldehyde systems the upper limits were higher than calculated, and the limit flames were usually fragmented. Similar behaviour was previously found for the phenol formaldehyde - magnesium oxide system, and a substantial proportion of the dust was not burnt in the flame[2].

The minimum percentage of diluent dust required to prevent propagation at any suspension concentration of the mixture, the peak value, was calculated as 87 per cent for phenol formaldehyde - barium sulphate and as 96 per cent for the polyethylene - magnesium oxide system. The experimental determinations, in the large scale tube apparatus, were within the range 90-95 per cent in both cases (Figs 6 and 7). In the small scale tests (Table 4) the ranges were 85-90 and 95-100 respectively. As the previous work with the large scale tube, using phenol formaldehyde - magnesium oxide, gave experimental and calculated values in the range 75-80 per cent magnesium oxide[2], the calculated peak values in the present work had changed noticeably with dust composition and followed closely the experimental values. This change gave further support to the assumptions on which the calculations were based, particularly because the dust mixture compositions would not be affected by irregularities of dispersion of the dust suspension.

The peak values mark the division between Class I and Class II dust mixtures, and for the phenol formaldehyde - barium sulphate system the calculated division was at 87 per cent diluent, feeble explosions were obtained with 90 per cent diluent in the large scale tube and the small scale tests indicated 85-90 per cent. Viewed on this basis the discrepancy between the results for the large and small scales was marginal and would be insufficient to require a reassessment of earlier work on Class I and Class II dusts[2, 3].

With polyethylene dust alone, the concentration was so low at the lower flammability limit that the calculated flame temperature (T_1) was only 790°K. The calculation was based on the assumption that the heat release in the flame was homogeneous. Visual observation of the flame indicated that the temperature was in fact much higher, and a likely explanation is that the flame was heterogeneous and consisted of hot gaseous regions interspersed with cold air. The means by which flame propagation occurs in such flames, and whether this explanation is correct, are currently being studied.

Further investigations with small scale apparatus

The experiments described in the Appendix were carried out to give further information on the amounts of various diluents required to prevent explosion in phenol formaldehyde resin. The results are shown in Figs 8 and 9 where the observed percentage of diluent dust required is plotted against the calculated value; which was derived from equation 3, numerical values of the properties of the resin, and the properties of the diluent

dusts (Table 6). The calculated percentages were based on the assumptions that the diluents did not decompose at elevated temperatures and that their effect was solely that of being a thermal sink. In both Figs 8 and 9 the calculated values were in good agreement with the experimental results for the following dusts: barium carbonate, barium sulphate, calcium carbonate, magnesium oxide, and sodium bicarbonate. The observed percentage of diluent required was greater than the calculated value for titanium dioxide, and was much lower for sodium iodide although this compound has a low specific heat (Table 6). Agreement between the calculated and observed values for calcium sulphate was satisfactory with hot coil ignition (Fig. 9), but the calculated value was much higher than observed when spark ignition was used (Fig. 8). Usually the Hartmann apparatus with the spark ignition slightly underestimated the amount of diluent required, when compared with determinations in the large scale vertical tube apparatus, whereas with hot coil ignition the percentage was slightly overestimated. Thus for the majority of diluents represented in Figs 8 and 9 the observed percentages required to prevent explosion in phenol formaldehyde resin should be reasonably correct for large scale determinations. In general, the agreement between the observed and calculated values was sufficiently close to give additional support to the assumptions on which the calculations were based. The agreement also implies that the dusts were sufficiently finely divided for the particle size not to be a controlling factor.

Further evidence of the behaviour of some of the diluents in suppressing coal dust explosions has been reported[7]. The results were generally in line with the present work, limestone and sodium bicarbonate being found of similar effectiveness, whereas calcium sulphate (gypsum) was rather more effective. Halides, particularly of sodium or potassium were markedly more effective than the other diluents.

The reason for the enhanced effectivensss of the alkaline metal halides was not established; two possible causes are firstly, there is a chemical effect in the flame, and secondly, the diluent interferes with the volatilisation of the fuel. On the basis of evidence at present available it is not possible to decide whether either of these alternatives is correct. A further point is that some of the diluents such as carbonates, bicarbonate, or hydrate, are not stable when exposed to high temperatures for long periods.

Nevertheless, in the current work, with the possible exception of calcium sulphate, the diluents appeared to behave as inert solids without decomposition. By using this assumption in conjunction with equation 3, the calculated percentages of diluents required to prevent explosions were close to the observed values. The same point of course also arises in connection with coal dust explosions. It is possible that in the short time interval available as the diluent enters the flame, which is probably of the order 10^{-1} to 10^{-2} s, the amount of decomposition would be small even though the temperature was high. Decomposition may occur in regions behind the flame front, but then it would be unlikely to substantially influence the behaviour at the front where flame propagation occurs. The apparent, and unexpected, stability of certain diluents together with the pronounced quenching effect shown by sodium iodide merit further study.

CONCLUSIONS

1. When barium sulphate was substituted for magnesium oxide, in mixtures with phenol formaldehyde resin, a higher proportion was required to prevent flame propagation in suspensions in a large scale vertical tube.

2. Replacement of phenol formaldehyde resin with polyethylene dust, in mixtures with magnesium oxide, led to an increase in the proportion of magnesium oxide required to prevent flame propagation in the same apparatus.

3. The theoretical treatment developed previously, and based on the assumption that the non-combustible dust acted as a heat sink, was in general agreement with the results.

4. Tests with further diluents, in small scale apparatus, also gave general support to the theory.

5. One exceptional material, sodium iodide was found to be markedly more effective in preventing flame propagation than would be expected from its thermal properties alone.

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APPENDIX

As previous results[2,3] have shown that the small scale Hartmann tests gave results close to those for the large scale vertical tube, as regards the proportion of diluent dust required to suppress explosions, the small scale tests were used for further investigations of the behaviour of other solid diluents. A survey was made with a number of diluents in the Hartmann apparatus and the percentages required to suppress explosion were determined. From the results it was hoped to obtain further information on the relation between the amount of diluent required and its thermal properties. The experiments were exploratory but, because of the relationship between the results for small scale and large scale apparatus obtained previously, there was justification for assuming that the tests would give realistic results for a number of diluents without needing to embark upon a long series of large scale experiments. In all tests the combustible dust was the phenol formaldehyde resin used on the large scale.

All the diluent dusts were either finely divided as received, or were ball milled for several hours. To aid the dispersion of some of the milled dusts a small amount of a flowing agent, magnesium stearate, was introduced before milling (Table 6). Good dispersability was important in the tests, because otherwise the mixtures would appear to be less explosible than in fact they were and the effect of the diluent would be overestimated. As magnesium stearate is a readily explosible dust[1], it was included with the combustible in the calculation of the percentage compositions of the mixtures. The results for magnesium oxide have already been reported[2], but are included for comparison, as are those for barium sulphate. Unless stated otherwise the specific heats given in Table 6 were calculated from published values[4], at a mean temperature of $\dfrac{T_1 + T_0}{2}$ i.e. 835°K.

Table 6

Properties of diluent dusts

Material	Formula	Flowing agent- per cent by weight	Mean specific heat
Barium carbonate	$Ba\ CO_3$	2	0.14 /
Barium sulphate	$Ba\ SO_4$	Nil	0.14
Calcium carbonate	$Ca\ CO_3$	1	0.29 /
Calcium sulphate	$Ca\ SO_4 \cdot 2\ H_2O$	1	0.27 /
Magnesium oxide	$Mg\ O$	Nil	0.28 *
Sodium bicarbonate	$Na\ H\ CO_3$	1	0.26 /**
Sodium iodide	$Na\ I$	1	0.13
Titanium dioxide	$Ti\ O_2$	1	0.23
Zirconium dioxide	$Zr\ O_2$	Nil	0.16

/   Assuming no decomposition

*   Ref. 2

**   Ref. 8

The phenol formaldehyde resin and diluent dusts were mixed using the method already described[2]. Small quantities of mixtures were then tested in the Hartmann and the modified Hartmann apparatus by upward dispersion over an electric spark or a hot wire coil respectively. Further details of the apparatus are given elsewhere[1]. Observation was made of whether flame propagated away from the source of ignition into the dust

suspension.   Tests were continued until two successive mixtures were
obtained one of which supported flame propagation and the other did not.
The proportion of diluent dust in the mixtures was usually varied in
steps of 5 per cent.

To check whether there might be preferential dispersion of one dust
in the mixture, a sample of a resin-zirconium dioxide mixture was dispersed
until only about one quarter remained.   Parts of the residue and of the
original mixture were ashed in a muffle furnace to constant weight. No
difference in composition was detected although the densities of the resin
and the zirconium dioxide particles differed markedly, being 1.2 and 5.7 g/cm^3
respectively.

The percentages of diluent dust required to prevent flame propagation
in mixtures with phenol formaldehyde resin are plotted as ordinates in
Figs 8 and 9, for the Hartmann and modified Hartmann apparatus respectively.
The values shown are the mean compositions between mixtures which just
ignited and those that just did not.   As mentioned before, the flowing agent
was included with the resin as combustible.
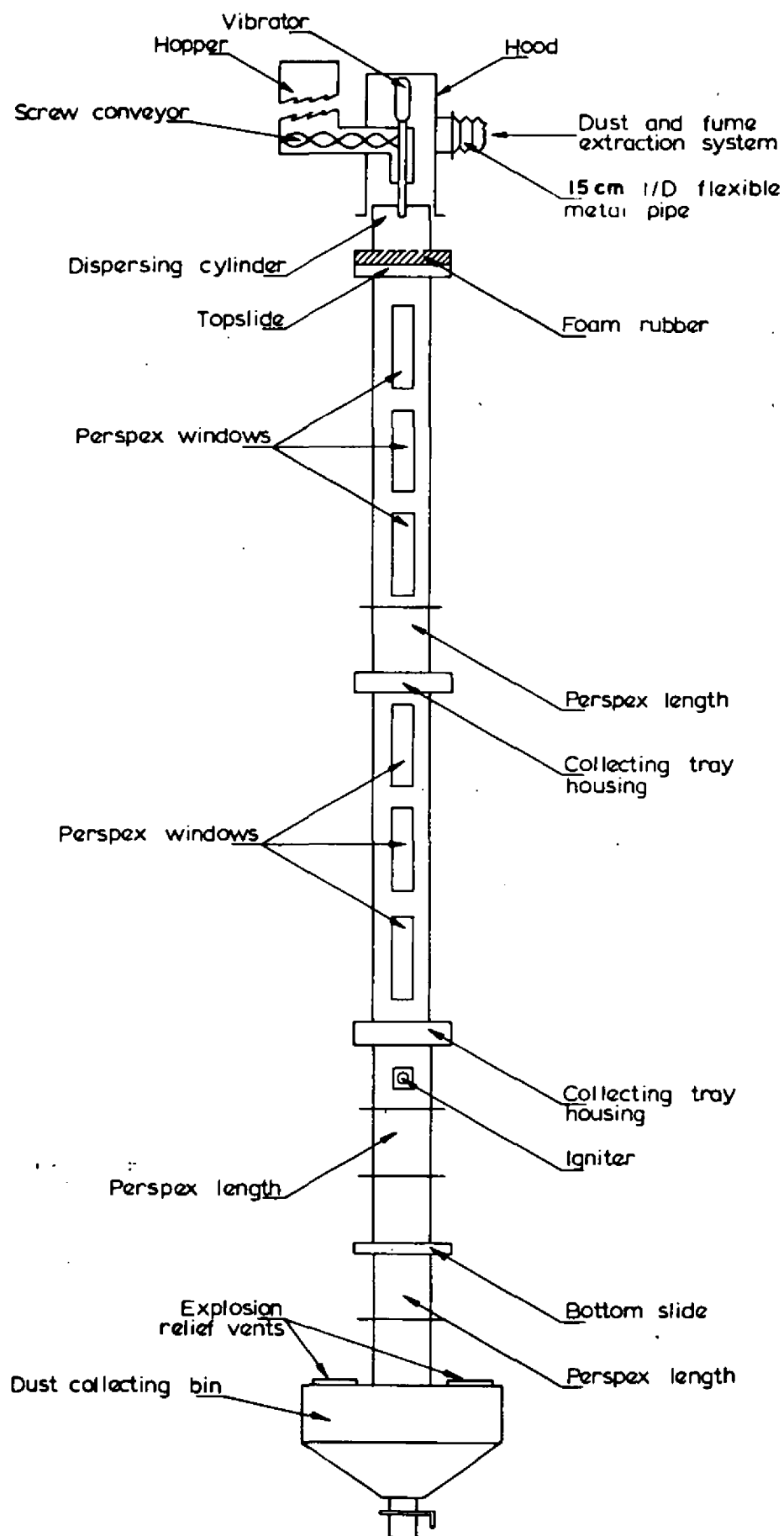
FIG. 1.   VERTICAL   25 CM   I/D   DUST   EXPLOSION   TUBE
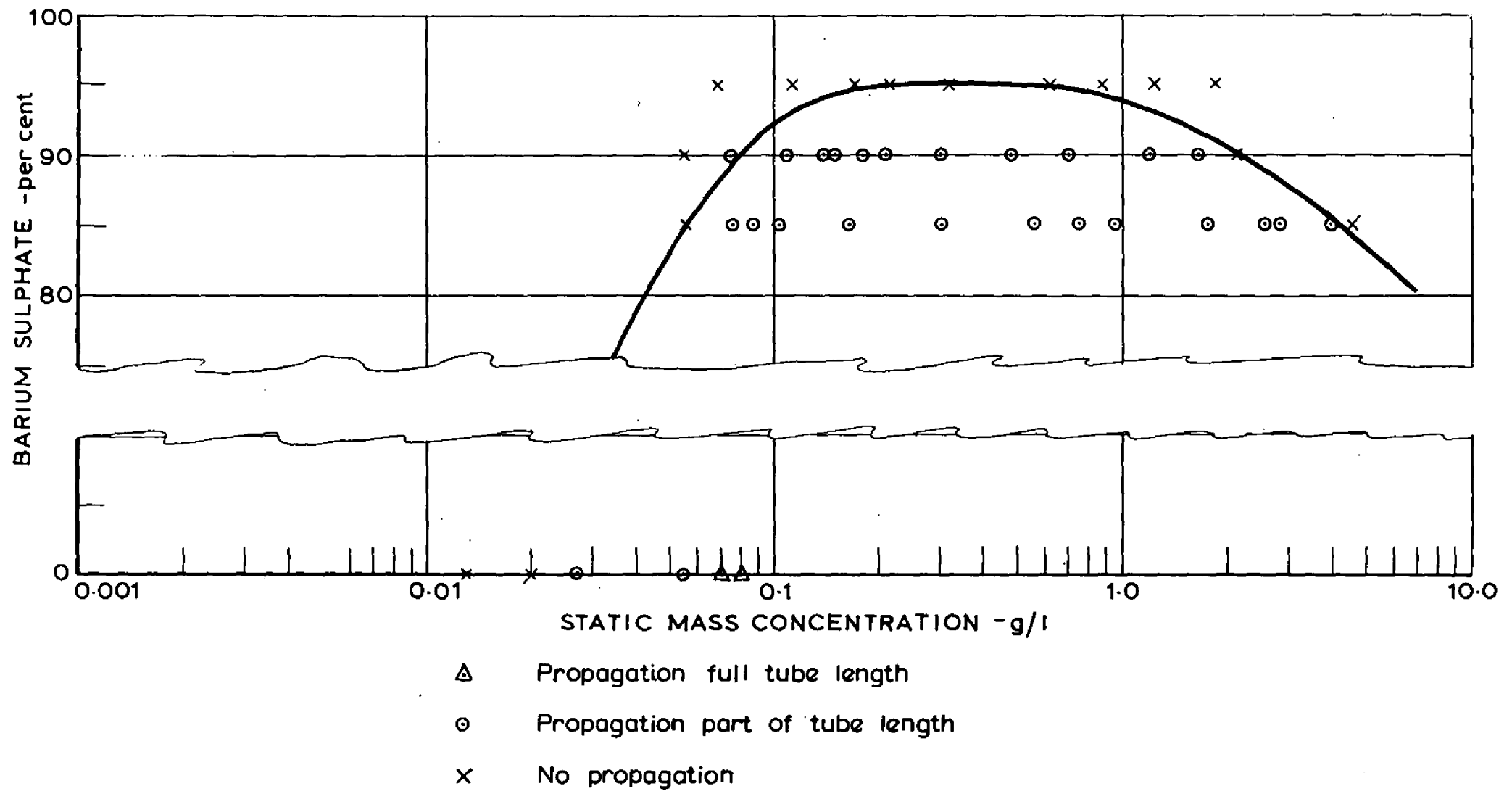
FIG.2. FLAMMABILITY LIMITS:
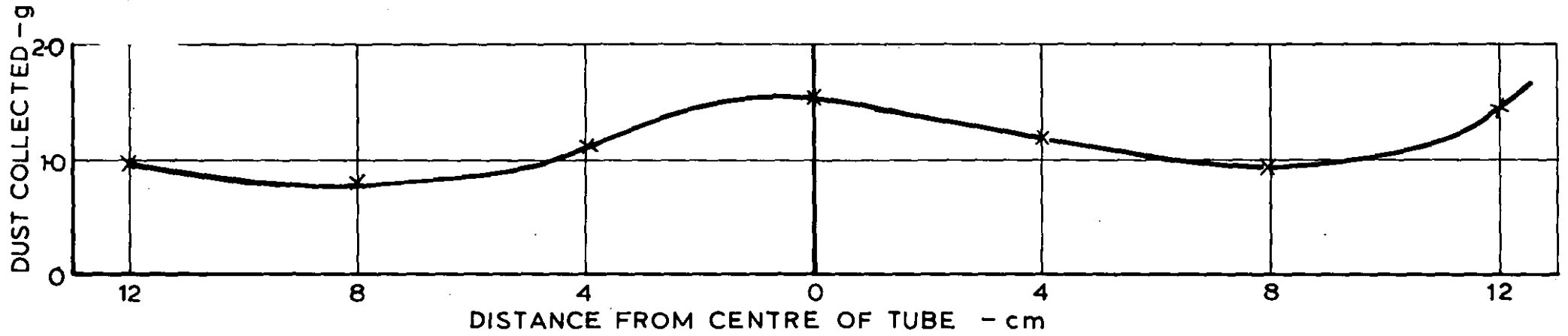PHENOLFORMALDEHYDE RESIN/BARIUM SULPHATE MIXTURES
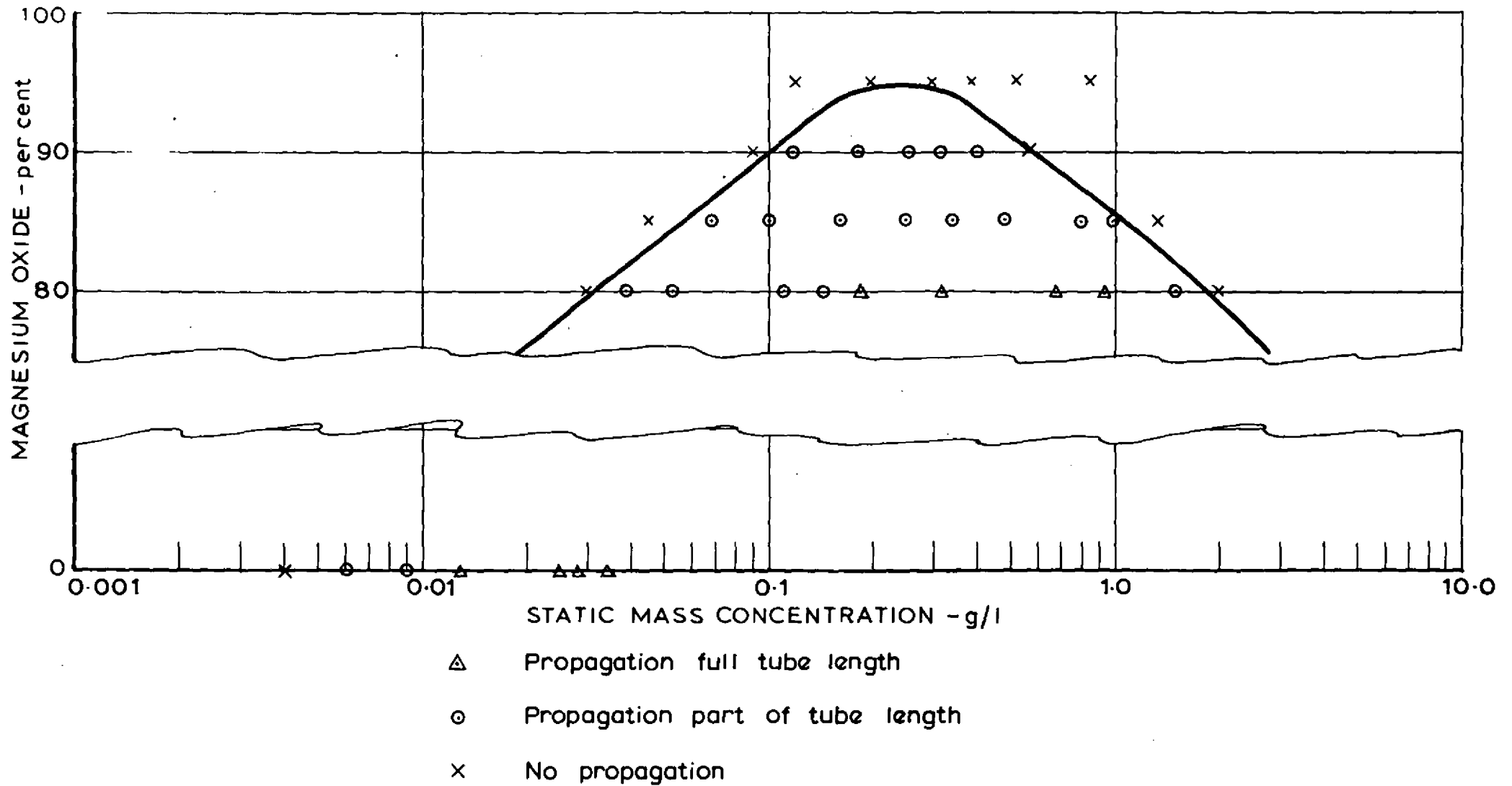
FIG.3. FLAMMABILITY LIMITS:
POLYETHYLENE / MAGNESIUM OXIDE MIXTURES

FIG.4. DUST DISTRIBUTION IN EXPLOSION TUBE ALONG A DIAMETER,
TUBE OPEN AT TOP, CLOSED AT BOTTOM
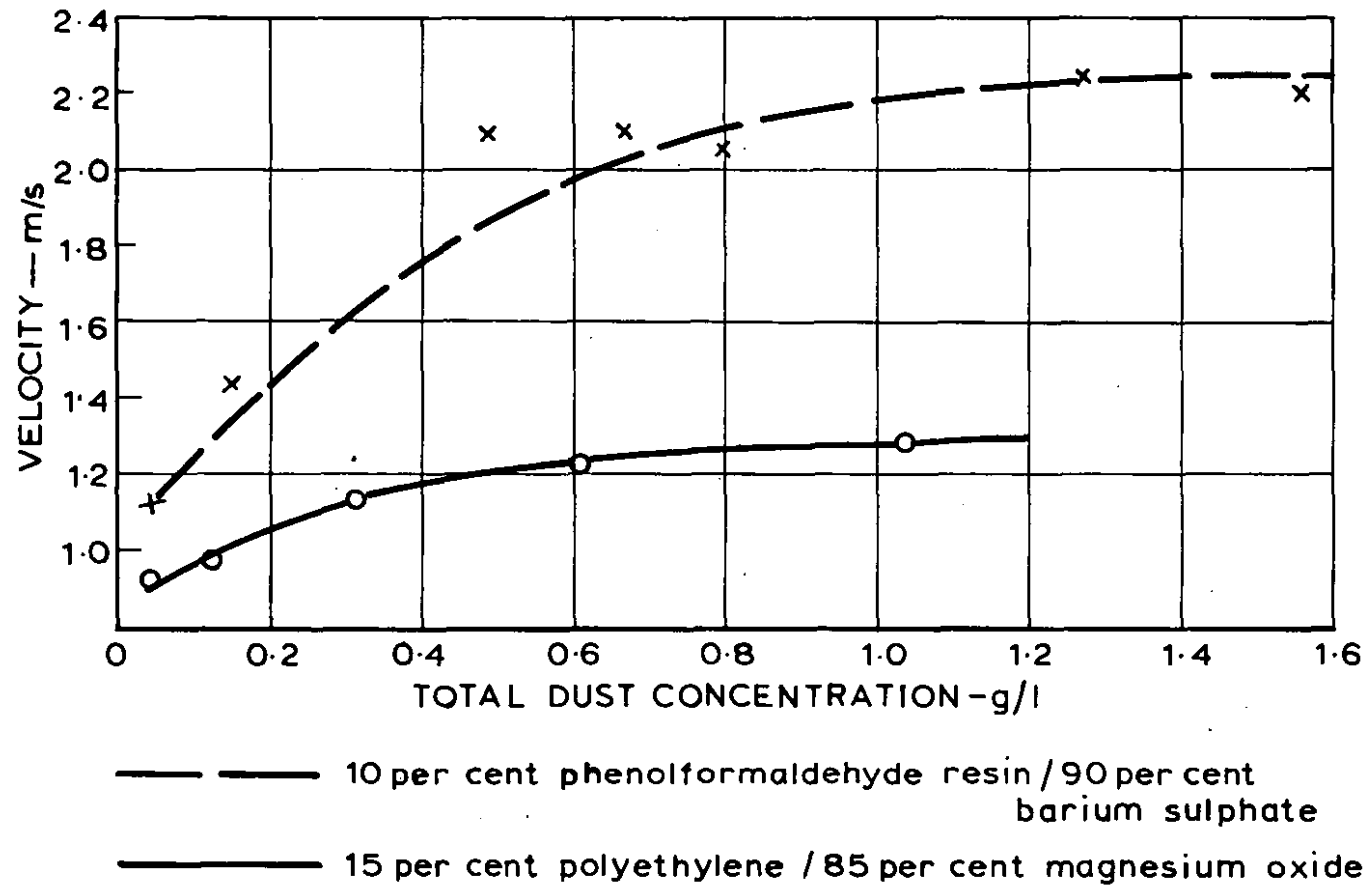
FIG.5.VARIATION OF DUST VELOCITY WITH CONCENTRATION
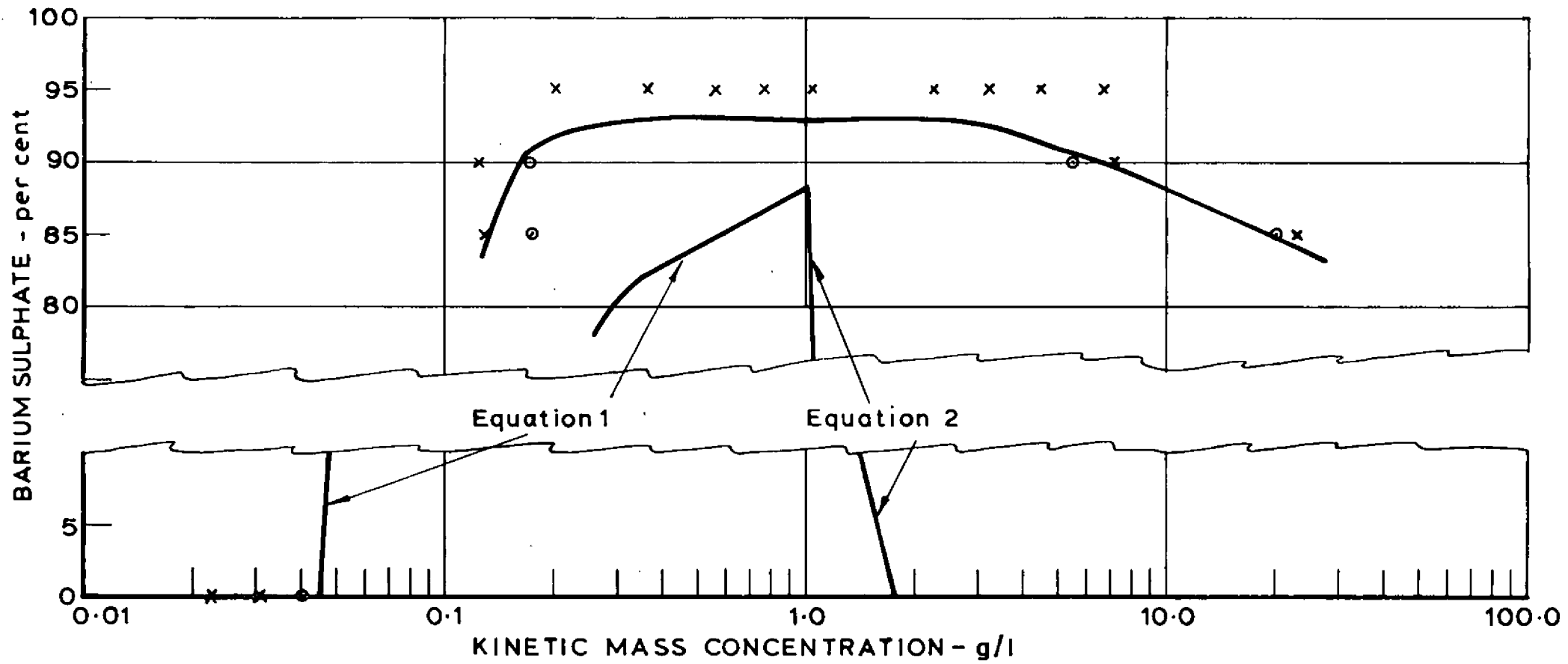
FIG.6. FLAMMABILITY LIMITS :
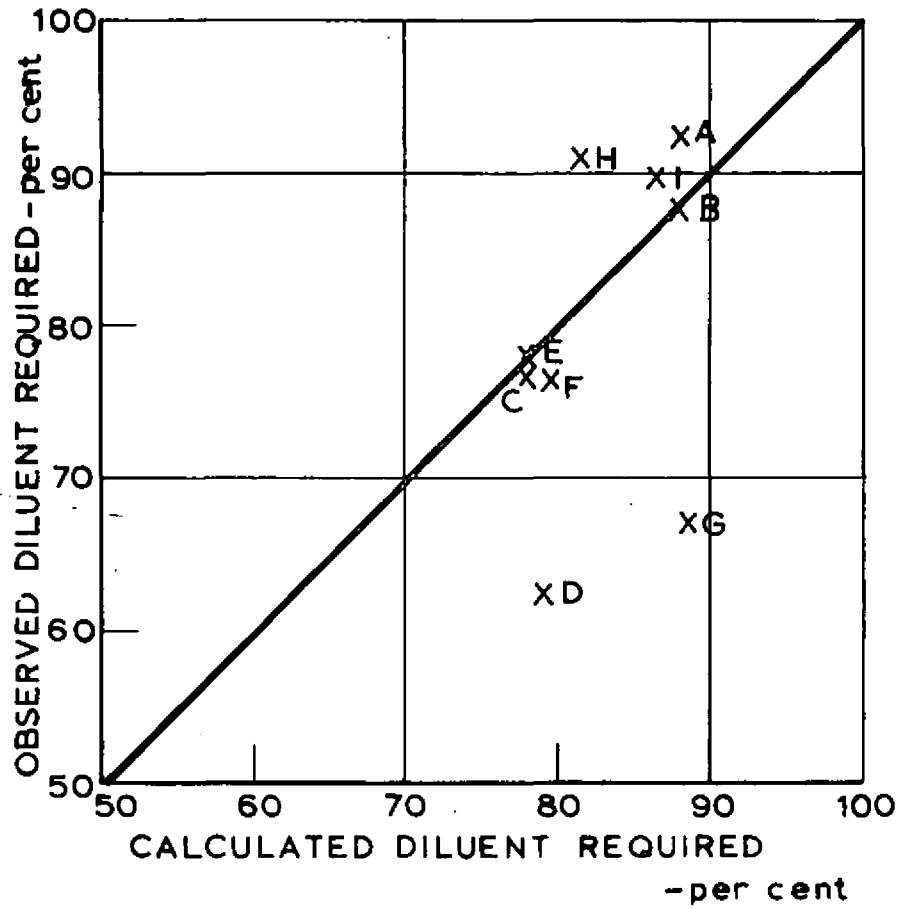PHENOL FORMALDEHYDE / BARIUM SULPHATE MIXTURES
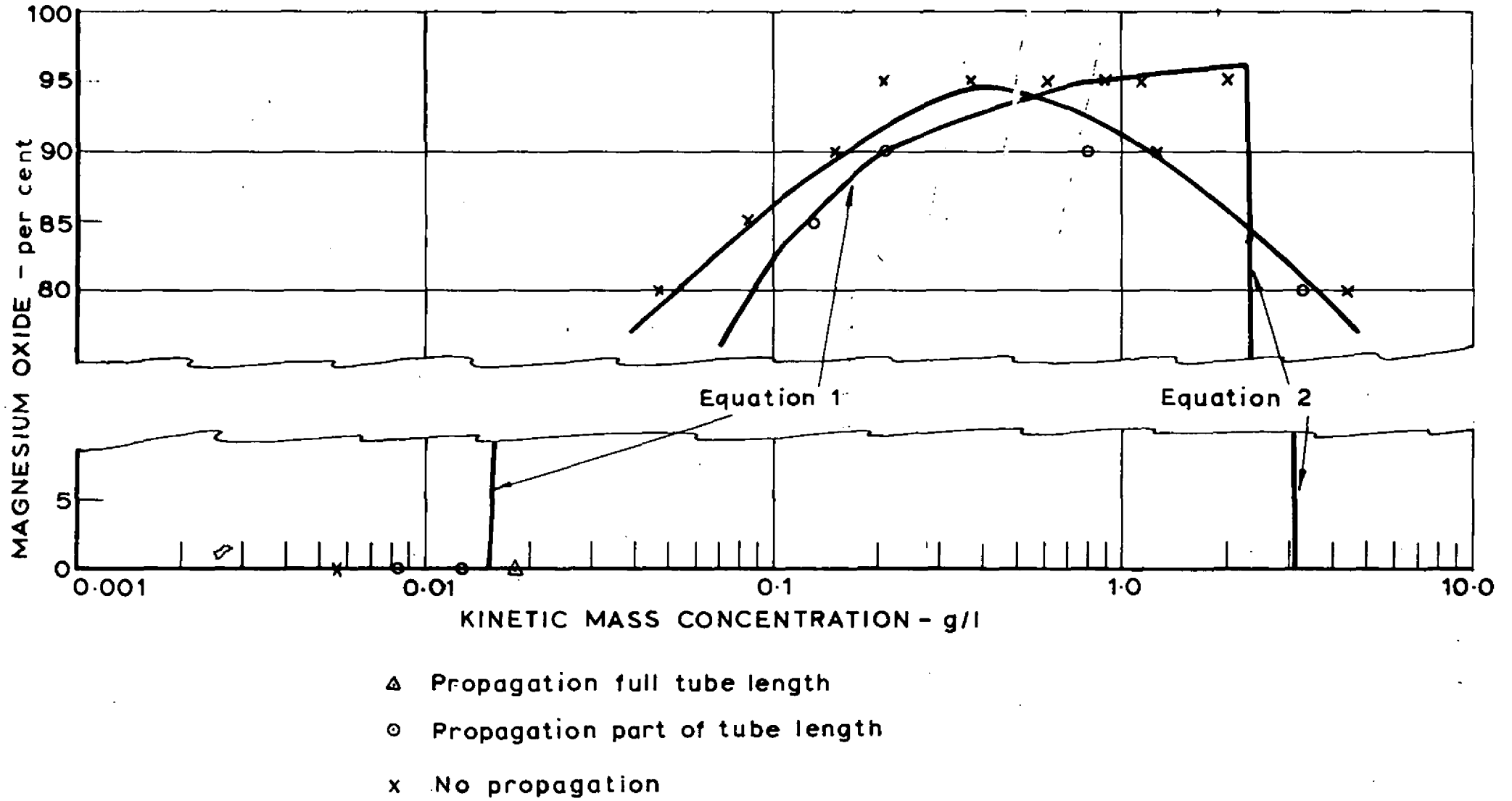
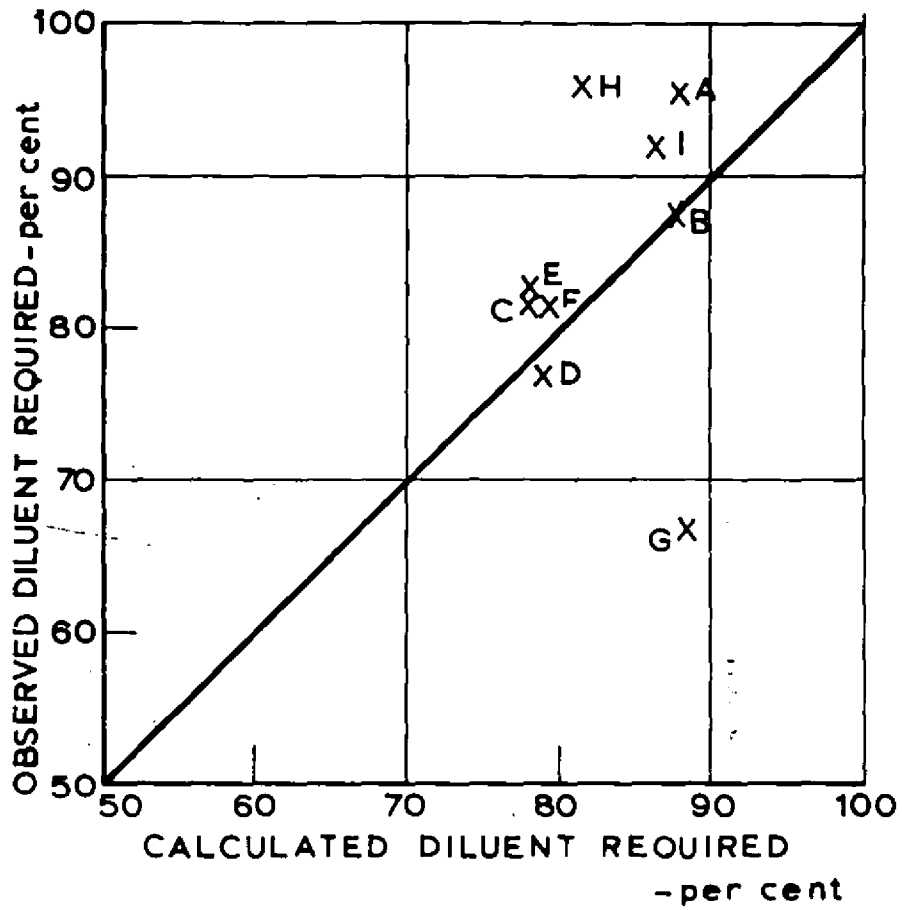FIG.7. FLAMMABILITY LIMITS
POLYETHYLENE / MAGNESIUM OXIDE MIXTURES

A – Barium Carbonate
B – Barium Sulphate
C – Calcium Carbonate
D – Calcium Sulphate
E – Magnesium Oxide
F – Sodium Bicarbonate
G – Sodium Iodide
H – Titanium Dioxide
I – Zirconium Dioxide

Hartmann apparatus with spark ignition

FIG. 8. PERCENTAGES OF DILUENT DUSTS
TO PREVENT EXPLOSION OF PHENOLFORMALDEHYDE
RESIN

A - Barium Carbonate
B - Barium Sulphate
C - Calcium Carbonate
D - Calcium Sulphate
E - Magnesium Oxide
F - Sodium Bicarbonate
G - Sodium Iodide
H - Titanium Dioxide
I - Zirconium Dioxide

Hartmann apparatus with coil ignition

FIG.9. PERCENTAGES OF DILUENT DUSTS
TO PREVENT EXPLOSION OF PHENOLFORMALDEHYDE
RESIN