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THE EFFECT OF PARTICLE SIZE ON THE MAXIMUM PERMISSIBLE OXYGEN CONCENTRATION TO PREVENT DUST EXPLOSIONS

F.K. SWEIS* and C.G. SINCLAIR
Department of Chemical Engineering, UMIST, Manchester M60 1QD (Great Britain)

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Summary

The oxygen concentration in the gas phase at the boundary between an explosion and no explosion in a dust cloud, y_o^b, has been investigated for several particle sizes and for mixtures of coarse and fine dusts of the same material. The maximum permissible oxygen concentration, y_o^m, at which no explosion is obtained has also been determined. Measurements for several type of materials were made in the modified version of the standard small vertical tube apparatus. Nitrogen was used as the inert gas and a train of sparks as the source of ignition. The results obtained indicated that the oxygen concentration is dependent on the particle size, that is, values of y_o^m decrease with a decrease in the size of the particles. Below 100 μm, values of y_o^m become almost constant. Admixture of fine dust as low as 5% to coarse dusts is sufficient to reduce the y_o^m values severely.

Introduction

Inerting is a method used to prevent dust explosions. The basic principle of the method is to dilute the dust atmosphere with inert gases such as nitrogen and carbon dioxide [1—4]. Its advantage is that the explosion is prevented at source, whereas other safety measures permit the explosion to start and then control it either by extinguishing or pressure relief.

Previously, the maximum permissible oxygen concentration to prevent ignition, y_o^m, has been found to depend on the particle size of the material [5]. Using carbon dioxide as the inert gas and a spark as the source of ignition, the y_o^m values were found to decrease sharply as the particle size of a sample of cornstarch decreased. Below a certain size, the y_o^m values were constant.

The experimental work presented in this paper was undertaken to extend the range of materials studied and to determine the effect of mixtures of particle sizes.

*Present address: Department of Chemical Engineering, College of Engineering, University of Jordan, Amman, Jordan.

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Materials

The materials studied were diphenylol propane (bisphenol A), benzoic acid, rice (white), citric acid and naphthalene. Dust samples of different particle sizes were prepared by sieving, and the particle size was determined as the geometric mean of apertures of the bracketing meshes. All the samples except naphthalene were dried at 75° C.

Equipment and procedure

A modified version of the standard small vertical tube apparatus used for checking the explosivity of dusts was used to determine y_o^m. The dimensions and constructional details are given by Raftery [6] and the modifications are shown in Fig. 1. The purpose of the modification was to prepare the required gas mixture by mixing air and nitrogen. The mixture was ananlysed with an oxygen analyser (Teledyne Analytical Instruments Type 320B) and stored in a slack balloon. The gas mixture after passing through the oxygen analyser and a pulsation damper was either used at low pressure for purging or compressed into the gas reservoir for dust dispersion in the usual way. The dispersed dust was ignited by a continuous electric discharge between two opposing brass electrodes mounted in the perspex explosion tube.

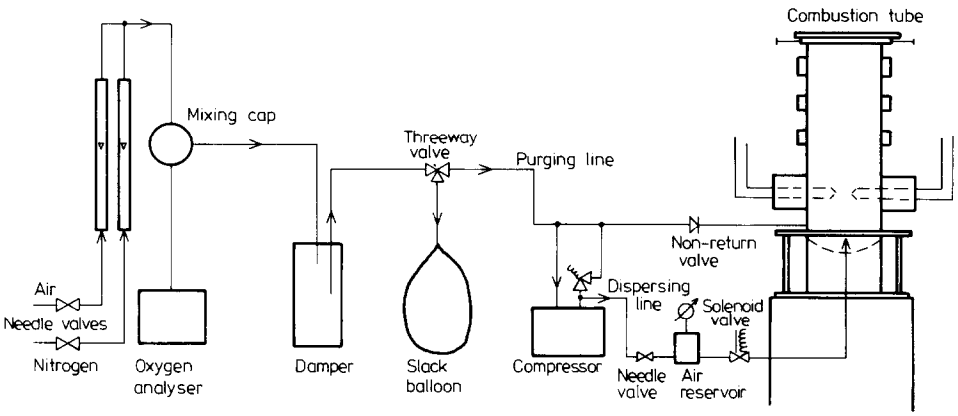

Fig. 1. Modified version of the small vertical tube apparatus.

A filter paper diaphragm with a small central 0.5-cm diameter hole was attached across the top of the explosion tube. The purge gas flowing through this diaphragm was monitored with an oxygen analyser to check that purging was complete. The procedure was as follows:

1. When the desired oxygen concentration had been achieved, the gas reservoir was emptied and refilled three times and then charged up to the desired dispersion pressure.

2. A weighed quantity of the dust was placed in the dispersion cup of the apparatus.
3. The gas mixture was allowed to flow through the explosion tube at a rate of about 5 l/min until the outlet concentration was the same as the inlet.
4. The ignition source was energised.
5. The full port solenoid valve was opened, and the dust was dispersed by a blast of the air/nitrogen mixture.

The criterion for indicating an explosion in the small vertical tube apparatus was the propagation of flame away from the ignition source; full flame propagation was usually accompanied by bursting of the filter paper diaphragm. When an explosion occurred, the oxygen concentration was reduced and testing was continued until no explosion was observed in three tests at the same dust concentration.

If no explosion occurred at the first attempt, further attempts were made to explode the dust by varying the pressure of the dispersion air/nitrogen mixture (40—50 lb/in^2) and/or varying the gap between the electrodes (0.5—1.0 cm). After each trial, the explosion tube was dismantled and cleaned and a fresh quantity of the dust placed in the dispersion cup between each attempt.

Further details of the equipment and procedure are given in Ref. [4].

Results and discussion

Effect of particle size on y_o^m

Figures 2 and 3 show the variation of the oxygen concentration in percent by volume with dust concentration (g/l) for benzoic acid (68.7 μm) and naphthalene (505 μm). They are representative of the results obtained. Each point on the graphs represent a group of three tests. If no explosion occurred or a part tube flame propagation was obtained at the first test,

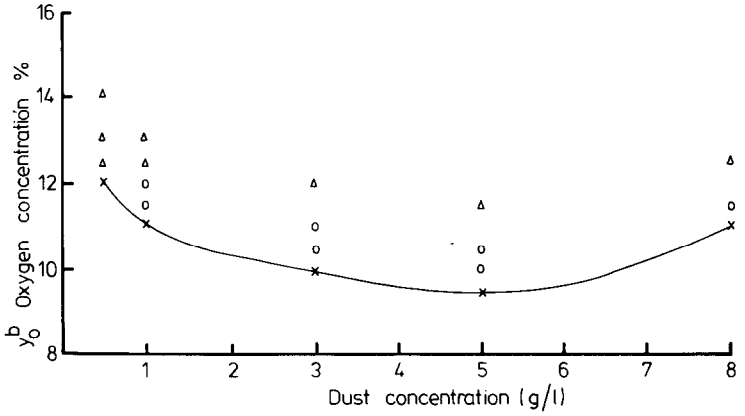

Fig. 2. The variation of y_o^b with dust concentration of benzoic acid — 68.7 μm.

further tests were carried out by varying the dispersing pressure of the gas mixture (40—50 lb/in^2) and/or varying the gap between the electrodes (0.64—1.5 cm). When the degree of flame propagation varied within a group, the point shown represents the most severe flame propagation. The symbols representing the degree of flame propagation on the sample figures are:

△ — full tube flame propagation, sometimes accompanied by bursting of the filter paper diaphragm,
○ — part tube flame propagation,
X — no flame propagation, i.e., no ignition.

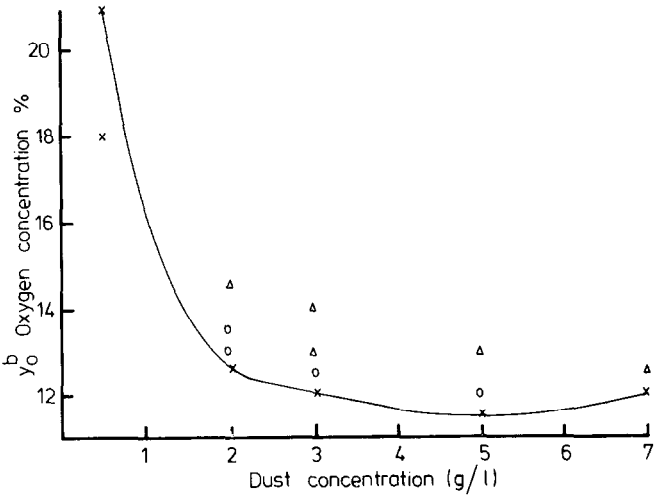

Fig. 3. The variation of y_o^b with dust concentration of naphthalene — 505 μm.

When an explosion occurred, the oxygen concentration was reduced by 0.5 percent and testing was continued until no explosion was observed in three tests at the same dust concentration.

In Figs. 2 and 3, it can be seen that as the dust concentration increased from 0.5 g/l to 3 g/l, the oxygen concentration, y_o^b, decreased moderately from 12% to 10% for benzoic acid and sharply from 21% to 12% for naphthalene. Values for the maximum permissible oxygen concentration, y_o^m, of 9.5% and 11.5% were obtained for benzoic acid and naphthalene, respectively, when the dust concentration was increased to 5 g/l. With a further increase in the dust concentration, y_o^b increased slightly for both materials.

Figures 4—8 show all the results for particles of uniform size. In general, all the figures show almost the same pattern as the sample curves and each curve shows a minimum which is taken as the maximum permissible oxygen concentration to prevent ignition, y_o^m.

As might be expected, the relationship between the variables of interest y_o^b, y_o^m (the minimum value of y_o^b) and x_o^m (the dust concentration corres-

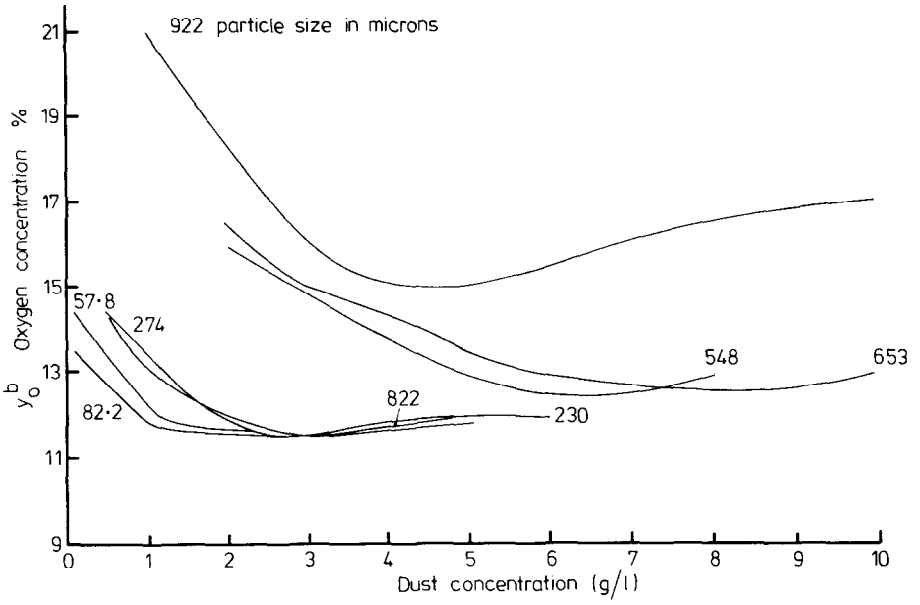

Fig. 4. The variation of y_o^b with dust concentration for all particle sizes of diphenylol propane.

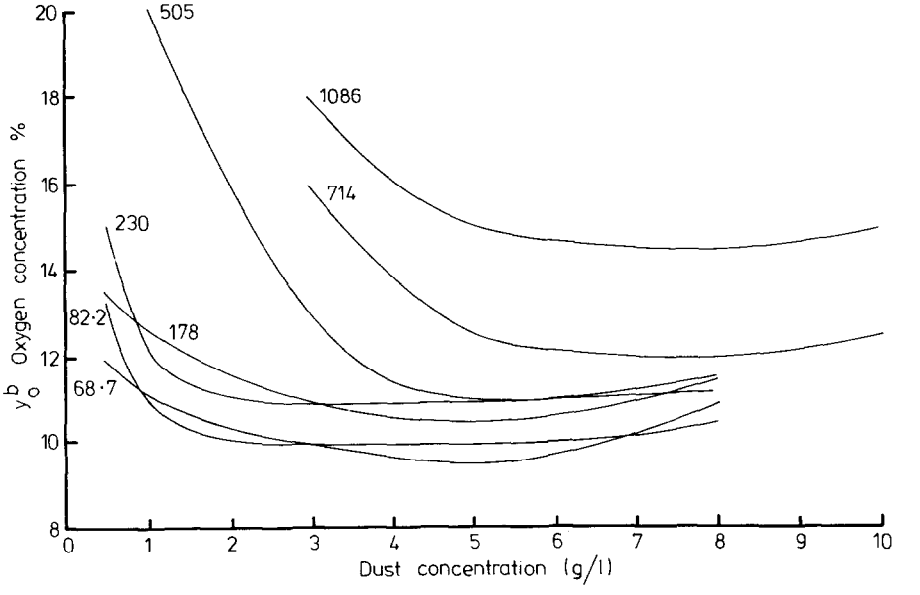

Fig. 5. The variation of y_o^b with dust concentration for all particle sizes of benzoic acid.

ponding to y_o^m) and the known parameters of the dust cloud, i.e., particle size, concentration and material properties, is complicated.

Figure 9 shows the effect of particle size on the maximum permissible oxygen concentration, y_o^m, for all the materials. It can be seen that large particle sizes of diphenylol propane, benzoic acid and naphthalene are much easier to ignite than those of rice and citric acid. This behaviour

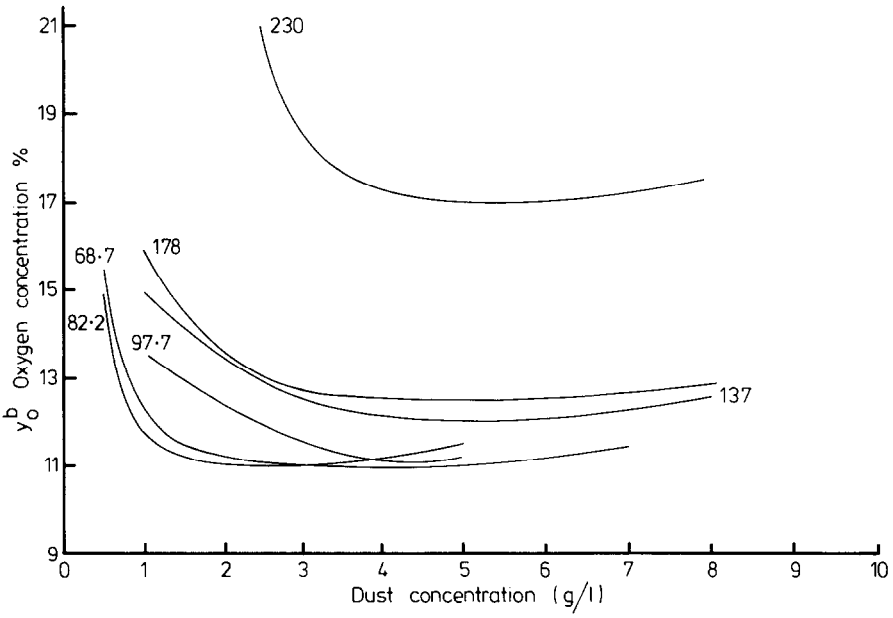

Fig. 6. The variation of y_o^b with dust concentration for all particle sizes of rice.

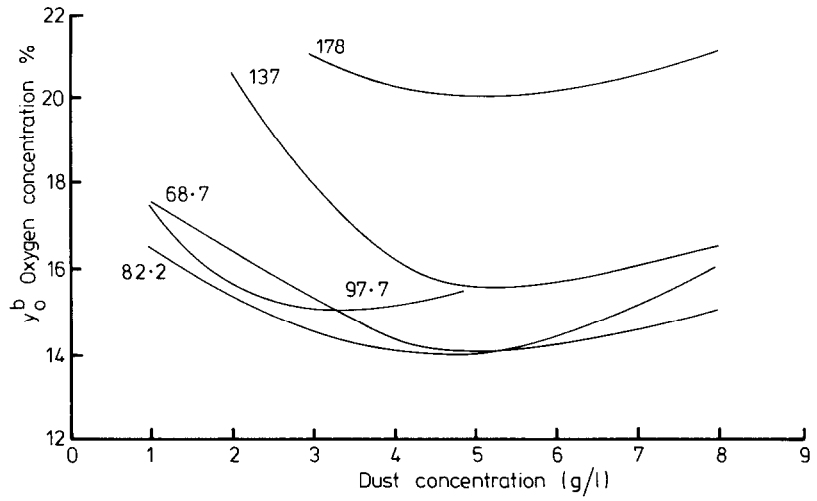

Fig. 7. The variation of y_o^b with dust concentration for all particle sizes of citric acid.

may be attributed to the reactivity of each material. The figure shows that with particle sizes less than 100 μm, values of y_o^m become almost constant for all the materials.

Table 1 lists values of y_o^m and x_o^m for all the particle sizes of the materials studied.

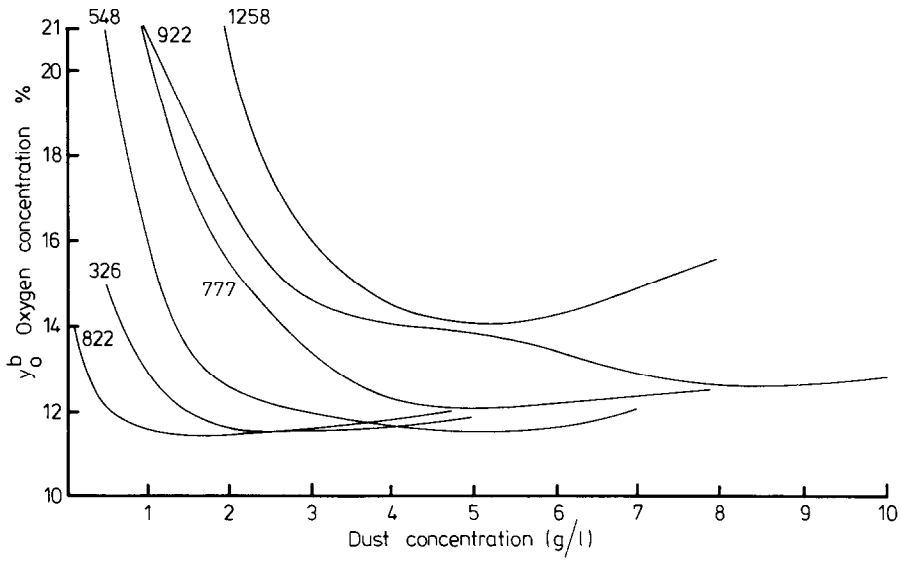

Fig. 8. The variation of y_o^b with dust concentration for all particle sizes of naphthalene.

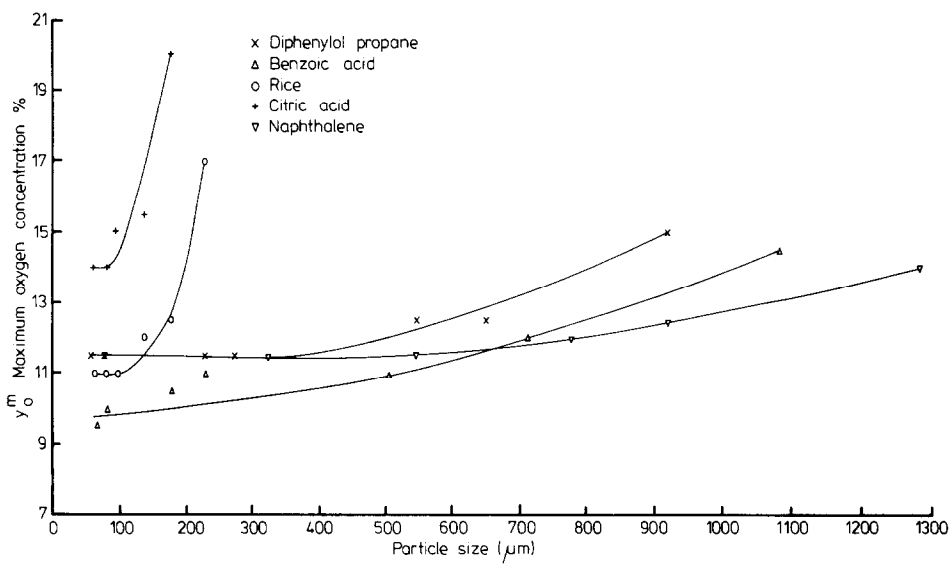

Fig. 9. The variation of y_o^m with particle size for all the materials.

TABLE 1

Values of y_o^m and x_o^m for all the materials

Material	Sieve size (μm)		Particle size (μm)	y_o^m (%)	x_o^m (g/l)
Diphenylol propane	-1000	+850	922	15	5
	-710	+600	654	12.5	8
	-600	+500	548	12.5	6
	-300	+250	274	11.5	3
	-250	+212	230	11.5	3
	-90	+75	82.2	11.5	3
	-63	+53	57.8	11.5	3
Benzoic acid	-1180	+1000	1086	14.5	8
	-850	+600	714	12	8
	-600	+425	505	11	5
	-250	+212	230	11	5
	-212	+150	178	10.5	5
	-90	+75	82.2	10	5
	-75	+63	68.7	9.5	5
Rice	-250	+212	230	17	5
	-212	+150	178	12.5	5
	-150	+125	137	12	5
	-106	+90	97.7	11	5
	-90	+75	82.2	11	3
	-75	+63	68.7	11	3
Citric acid	-212	+150	178	20	5
	-150	+125	137	15.5	5
	-106	+90	97.7	15	3
	-90	+75	82.2	14	5
	-75	+63	68.7	14	5
Naphthalene	-1400	+1180	1285	14	5
	-1000	+850	922	12.5	8
	-850	+710	777	12	5
	-600	+425	505	11.5	5
	-355	+300	326	11.5	3
	-90	+75	82.2	11.5	3

Effect of mixtures of particle sizes on y_o^m

In a practical situation, dusts are not usually of uniform particle size and it is necessary to know the influence of the particle size distribution on the y_o^m value. For each material, mixtures of particles which had the lowest and highest values of y_o^m were made and the y_o^m of the mixture determined in the usual manner. The results are shown in Figs. 10—14 and summarised in Fig. (15).

The general pattern of results for any material is similar both for the

single particle size and the mixtures as can be seen by comparing corresponding figures (for example Figs. 5 and 11). The most important result of these tests is the highly non-linear relationship between the composition of the dust mixture (percent by weight of large particles) and the value of y_o^m. Thus, for example, an admixture of 5% by weight of fine particles with coarse reduces the y_o^m for rice and citric acid by 60% of the difference between the coarse and fine values. For these particles the ratio of particle diameters of coarse to fine was of the order of 3 to 1. For the other materials, which have a diameter ratio of roughly 16 to 1, the reduction in y_o^m was between 70 and 85% of the difference.

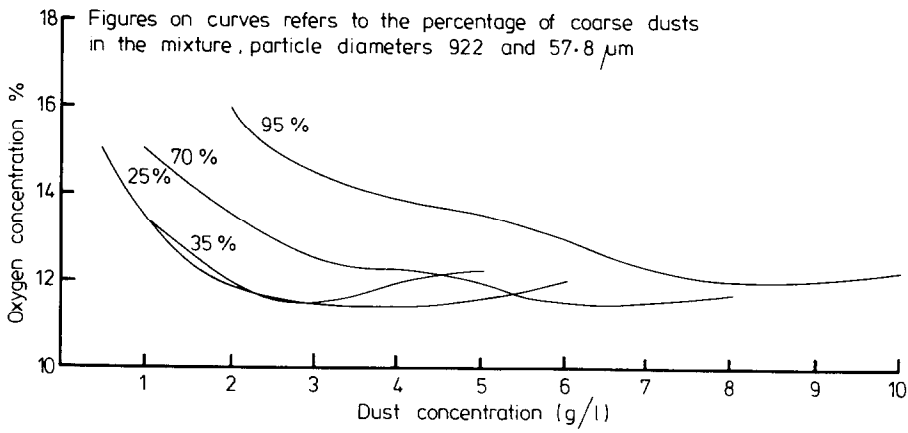

Fig. 10. The variation of y_o^m with dust concentration for all the mixtures of diphenylol propane.

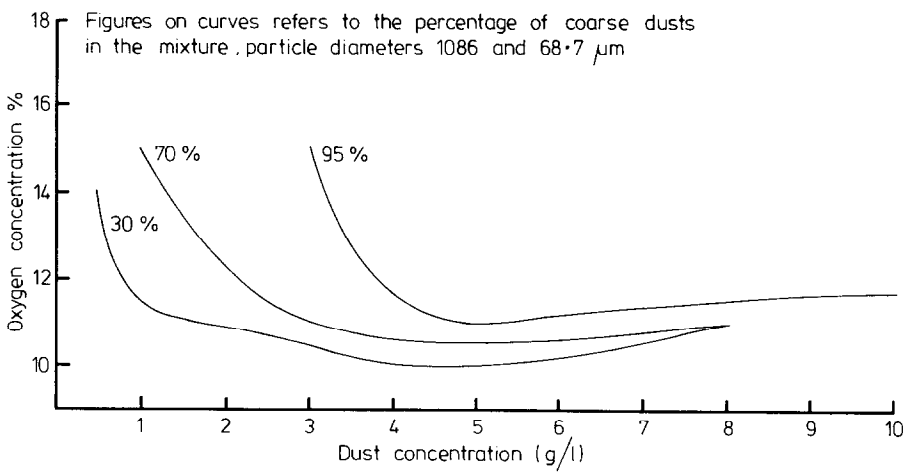

Fig. 11. The variation of y_o^m with dust concentration for all the mixtures of benzoic acid.

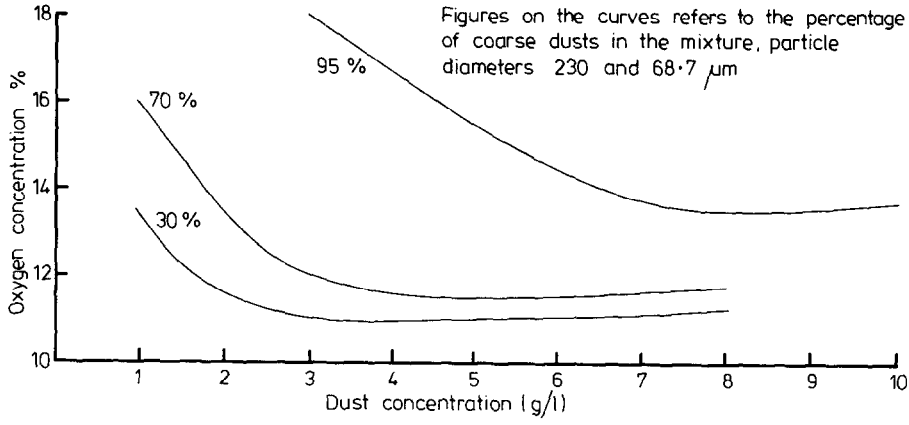

Fig. 12. The variation of y_o^m with dust concentration for all the mixtures of rice.

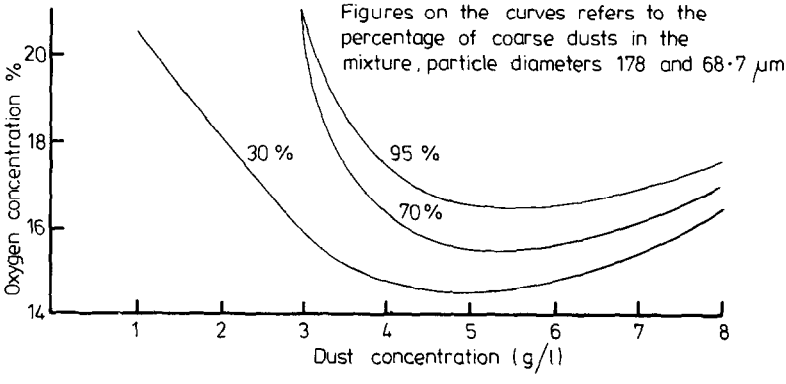

Fig. 13. The variation of y_o^m with dust concentration for all the mixtures of citric acid.

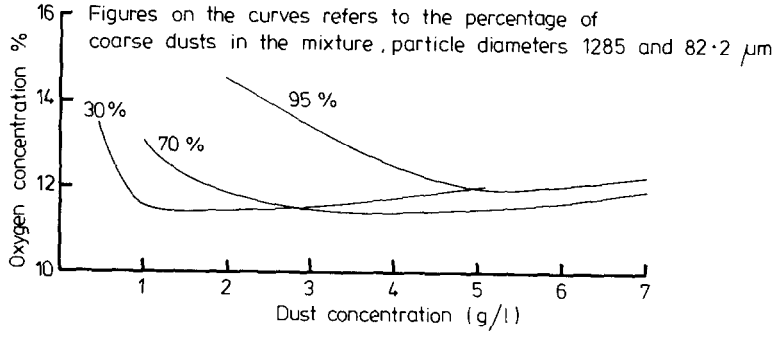

Fig. 14. The variation of y_o^m with dust concentration for all the mixtures of naphthalene.

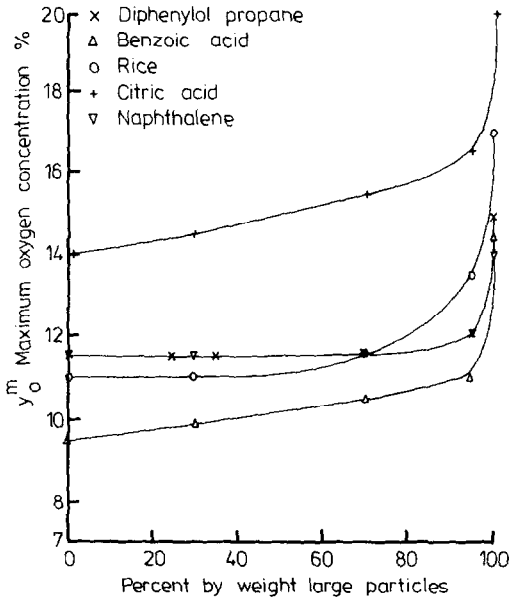

Fig. 15. The variation of y_o^m *with percent weight of coarse dusts in the mixtures for all the materials.*

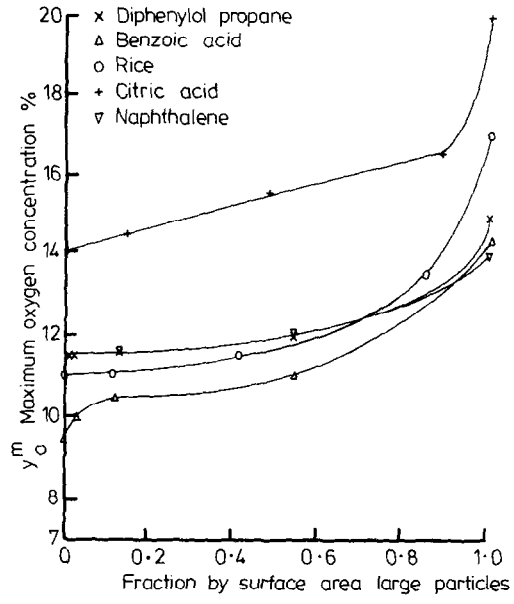

Fig. 16. The variation of y_o^m with the fraction of the total surface area for large particles.

Since y_o^m might be thought to be more closely related to surface area than to bulk mass of particles, the data presented in Fig. 15 have been recalculated in terms of surface area fraction contributed by the coarse and find particles. The appropriate relation is

$$f = \frac{W}{W + (1 - W)\, d_c/d_f}$$

where f is the fraction of the total surface area from coarse particles, W is the fraction of the total weight from coarse particles, d_c is the coarse particle diameter, and d_f is the fine particle diameter. This assumes that the shape factors of coarse and fine particles are identical for any given material. The results are plotted in Fig. 16 but do not show any useful correlation.

Conclusions

The maximum permissible oxygen concentration which will prevent explosion in dust clouds, y_o^b, depends on the particle size of the dust, its chemical reactivity and its concentration. For the material studied y_o^b decreased with particle size and showed a minimum in the range 1 to 10 g/l with the most probable value around 5 g/l.

The parameter y_o^m, which is the minimum value of y_o^b for a given material and particle size, is of most use for developing inerting systems to prevent dust explosion. It was found that y_o^m decreased with particle size (as also did y_o^b), becoming effectively constant for particle sizes less than 100 μm. It was also found that where fine particles were mixed with coarse particles the value of y_o^m for the fine particles most influenced the value of y_o^m for the mixture, and that as little as 5% by weight of fine particles would reduce the y_o^m by at least 60% of the total possible reduction. It is concluded therefore that for industrial dusts y_o^m should be determined for particle sizes less than 100 μm. If such do not exist nor can be formed during processing, y_o^m should be determined for the 5% weight fraction of dust at the lower particle diameter.

List of symbols

d_c	particle diameter of coarse dust	m
d_f	particle diameter of fine dust	m
f	fraction of the total surface area from coarse particles	
W	fraction of the total weight from coarse particles	
x_1	dust concentration	g/l
x_o^m	dust concentration at which y_o^m was obtained	g/l
y_o^b	maximum permissible oxygen concentration to prevent ignition of a particular concentration of the given dust	%

y_o^m	maximum permissible oxygen concentration to prevent ignition of all concentrations of the given dust	%

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