Fire Research Note No 1028

MAXIMUM PERMISSIBLE OXYGEN CONCENTRATIONS TO PREVENT DUST EXPLOSIONS IN A LARGE SCALE VERTICAL EXPLOSION TUBE

by

P S Tonkin

February 1975

LIBRARY REFERENCE ONLY

FIRE RESEARCH STATION

Fire Research Station
BOREHAMWOOD
Hertfordshire WD6 2BL

Tel: 01 953 6177

FR NOTE NO 1028
FEBRUARY 1975

MAXIMUM PERMISSIBLE OXYGEN CONCENTRATIONS TO PREVENT DUST EXPLOSIONS IN A LARGE SCALE VERTICAL EXPLOSION TUBE

by

P S Tonkin

SUMMARY

Maximum permissible oxygen concentrations for the prevention of explosions have been determined for phenol-formaldehyde resin and diphenylol propane dusts.

Nitrogen was used as the diluent gas with both dusts and carbon dioxide was used with phenol-formaldehyde resin only.

The values obtained in the work are compared with those obtained in the standard furnace test and with those obtained with a spark tube apparatus.

The results are also considered for provision of guidance for application to the safe and economical working of industrial plant.

Department of the Environment and Fire Offices' Committee
Joint Fire Research Organization

FR NOTE NO 1028
FEBRUARY 1975

MAXIMUM PERMISSIBLE OXYGEN CONCENTRATIONS TO PREVENT DUST EXPLOSIONS IN A LARGE SCALE VERTICAL EXPLOSION TUBE

by

P S Tonkin

INTRODUCTION

The prevention of explosions in dust clouds by reducing the oxygen concentration in the supporting atmosphere has been recognised for many years. However, its use has been restricted in industry for several reasons, one of these being the cost of the quantities of inerting gas apparently required which can make the method unacceptable economically.

Application of the method to industrial installations is based on measurements of the limiting oxygen concentrations obtained in a laboratory scale standard furnace test. However, the hot surface of the furnace tube has two effects

(a) the heating of the dust cloud to temperatures considerably above ambient and
(b) the provision of a large source of ignition.

These conditions constitute a severe test, and for many explosible dusts give values for maximum permissible oxygen concentrations, of 5 per cent or less by volume[1]. Such values make the inerting of atmospheres in industrial plant very costly and represent thermal conditions that would not often arise.

The many new processes in industry and the much wider use of materials in dust form that have occurred since the furnace test was adopted as the criterion for maximum permissible oxygen concentrations are factors which have, in recent years, caused the validity of the application of the small scale results to industrial plant to be questioned.

It has been suggested that the furnace test gave unnecessarily low oxygen values for many industrial processes, particularly for those industrial plants which excluded large sources of ignition compatible with that of the furnace test. Thus it was considered necessary at the Fire Research Station to determine inerting requirements in apparatus of industrial proportions and to compare the results so obtained with those determined in the furnace test.

Work has therefore been carried out at the Fire Research Station in a large scale vertical explosion tube apparatus to determine maximum permissible oxygen concentrations to prevent explosions in dust clouds of phenol-formaldehyde resin and diphenylol propane, as examples of industrial dusts and nitrogen and carbon dioxide as the inerting gases.

EXPERIMENTAL

Materials

The phenol-formaldehyde resin, which had the same properties as that used in previous work[2], was an industrial moulding powder of mean particle diameter 15 microns, containing 4.1% moisture.

The diphenylol propane used in the work was an industrial powder with a mean particle diameter of 122 microns and a moisture content of 0.6%.

The nitrogen and carbon dioxide gases used were commercial grades, each with less than 0.5 per cent impurities, confirmed by chromatographic analysis.

Apparatus

The experiments were carried out in the 0.25 m (10 inch) internal diameter 5.22 m (17.2 ft) long vertical explosion tube apparatus used in previous work[2] but modified to allow its use with premixed gas mixtures instead of air, (Fig 1).

One of the necessary modifications to the original explosion tube was the provision of inlet and outlet pipes at the bottom and top of the tube respectively for filling the tube with the various gas mixtures. A main flow of gas was used to fill the apparatus with the required atmosphere and a small 'trickle' flow was passed through the tube throughout each experiment to maintain that atmosphere, by the system described below.

Short outlet pipes, one near the top of the tube and one near the igniting position, were welded to the explosion tube to enable samples of the gas mixtures to be withdrawn and continuously analysed for oxygen content. Holders for filter pads were fitted to these outlet pipes and 16 mm ($\frac{5}{8}$ inch) internal diameter plastics tubing was attached to the filter housing to extract dust free gas for analysis of oxygen content. Two pumps were used in this system, one a rotary type, pumped at the rate of 57 l/min (2 ft^3/min) and was used to quickly purge the sampling lines only and the other, a diaphragm pump, was regulated to pass the gases over the analyser sensor at the rate of 1.5 l/min (0.05 ft^3/min), (Fig 2).

The tube arrangement used for the explosions was that of bottom closed and top open, with ignition near the closed end. Modifications to the top of the original explosion tube were necessary in order to comply with these conditions and, particularly, to prevent the entrainment of air into the explosion tube during dust delivery from the screw feeder (Fig 1) and its dispersion in the explosion tube. Consequently, the top of the explosion tube was modified as shown in Fig 1. The modification consisted of fitting a readily available 'crosspiece' 0.25 m (10 inches) diameter at the top of the tube, blanking off one of the horizontal side arms and fitting a 90 degrees bend to the arm opposite the blank. The top surface of the 12.5 mm (0.5 inch) thick, 51 mm (2 in) wide top flange of the bend was machined in order to effect a seal with a hinged cover of magnetised rubber composition, weighted with steel strips which operated as a 'flap valve', opening at a pressure of a few inches water gauge. Fig 3 shows the cover in more detail. During an explosion the gases and dust discharged through the flap valve into a sheet metal hood through which air was drawn at 26 m^3/min (900 ft^3/min) by an exhauster fan situated outside the building.

So that the explosion tube could be filled with the required atmosphere by the method of displacement it was necessary to modify the top of this tube as follows: an equal 2.5 inch BSP 'Tee' piece (T1 Fig 1) was fitted between the top of the dust dispersing cylinder and the delivery pipe of the screw feeder. To the sidearm of this 'Tee' was fitted an unequal BSP 2.5 in/0.75 in 'Tee' (T2 Fig 1). To the standard 2.5 inch diameter outlet of this 'Tee' was fitted a fullway valve (V Fig 1) which when open allowed the gas mixtures to flow through a length of flexible piping to the atmosphere outside the building. The standard 0.75 inch diameter outlet from the 'Tee' piece (T2 Fig 1) allowed gas mixtures to flow through flexible piping to the atmosphere outside the building throughout the experiments, including the period for trickle flow only, when the valve (V Fig 1) was closed.

The arrangement at the top of the tube, described above, enabled the gas mixtures to fill the apparatus up to the point at which the dust was delivered from the screw feeder and the 'trickle' gas flow ensured a small positive internal pressure throughout the experiments, preventing the entraining of air during experiments.

Supply of gas mixtures

Independent systems were used for main and trickle supplies. Air for the main inert gas/air mixtures was supplied by a centrifugal fan capable of delivering quantities up to 1.1 m^3/min (40 ft^3/min). Air for the 'trickle' flow was taken from the laboratory supply system.

The regulated supplies of nitrogen and carbon dioxide from gas cylinders and of air from the fan and the laboratory supply were each measured by taper tube and float type flow meters into the piping systems at speeds of flow which were conducive to turbulent mixing. The nitrogen or carbon dioxide were injected into the air stream in both main and 'trickle' flow systems.

The gas pressure reducing valve on the carbon dioxide cylinder and the pipeline adjacent to it were heated with warm air and a 200 watt line heater to prevent sublimation of solid carbon dioxide.

Dust supply

Dust was supplied by a screw feeder to a vibrating cylinder, with a perforated plate as its bottom, which dispersedthe dust to form a falling cloud in the explosion tube. A full description is given elsewhere[2].

Ignition source

A jet of burning propane/air mixture, injected into the dust cloud was used as the igniting source. The system used is described in detail elsewhere[2].

Oxygen analysis

The oxygen concentrations in the gas mixtures were measured using a polarographic apparatus, the values being recorded by a strip chart recorder. The oxygen concentration values obtained from the analyser did not vary by more than ± 2.0 per cent of the values calculated from the metered gas flow data (eg 10.0 ± 0.2).

Fig 2 shows, diagrammatically, the method used to bring the gas mixtures from the explosion tube to the oxygen analyser sensor.

General procedure

The general procedure used in the work was firstly to measure the dust concentration in the explosion tube, and then carry out a series of three explosion tests filling the tube with gas mixture with a particular oxygen content for each test. This was repeated at various dust concentrations with that gas mixture until the required flammable dust concentration range was obtained. (Figs 4 to 6). After starting with air the oxygen concentration

in the gas mixture in the explosion tube was reduced, further triplicate tests made, and the required flammable dust concentration ranges obtained, until an oxygen value was reached at which no explosion occurred with any dust concentration. This oxygen value was taken to be the maximum permissible oxygen concentration to prevent explosions in the vertical tube apparatus.

Experimental procedure

Dust concentrations were determined by collecting and weighing dust trapped in a known volume of the explosion tube and calculating the mass per unit volume. The dust concentration was determined at the outset and then checked during each series of three tests, if the variation exceeded $\pm$ 5% the series was rejected.

The atmosphere in the tube was sampled alternately from each sampling point when the gas mixture was being passed into the explosion tube, the oxygen concentration measured by the sensor being recorded continuously. When the atmosphere in the explosion tube contained the required oxygen concentration, as indicated by the results from the oxygen analyser, the main gas flow was stopped, and the valve (V Fig 1) in the effluent gas pipeline, at the top of the explosion tube, closed simultaneously, but the 'trickle' gas flow and the analysis of the gas withdrawn from the explosion tube near the igniter position were continued. The dust was introduced into the explosion tube from the vibrating cylinder and when dust was falling throughout the length of the tube and steady conditions had been attained (within a maximum time of 15 seconds) the slide (S Fig 1) near the igniter position, was closed and the igniting flame was immediately injected into the dust cloud. Observation was then made as to the extent of flame propagation in the explosion tube. If flame propagated upwards more than 0.61 m (2 ft) the result was recorded as a propagation, if flame travelled less than that distance it was recorded as a non-propagation.

The fan, drawing air through the hood at the top of the tube was started at the cessation of flame propagation in the explosion tube and after each experiment the explosion tube was purged with air until the oxygen analyser indicated complete removal of gaseous products of combustion.

Results

The results are presented as curves of boundaries (a) between points representing flame propagation less than 0.61 m (2.0 ft) and points representing flame propagation more than 0.61 m (2.0 ft) but less than the full length of the tube and (b) between the latter points, and those representing flame propagation throughout the length of the tube. Each point on the graphs represents the extent of flame propagation for the groups of three tests; where the extent of flame propagation varied within a group the point shown indicates the most extensive flame propagation.

Limiting values of dust-concentrations for flame propagation in atmospheres containing various concentrations of oxygen produced curves (Figs 4-6) which were flat bottomed rather than exhibiting sharp minima.

Fig 4 is a plot of the results from experiments in which phenol-formaldehyde resin was the fuel and nitrogen the diluent gas.

Fig 5 shows the results of experiments in which diphenylol propane was the fuel and nitrogen the diluent gas.

Fig 6 shows the results obtained from experiments with phenol-formaldehyde resin as fuel and carbon dioxide the diluent gas.

The maximum permissible oxygen values have been included in Table 1 below.

DISCUSSION

Since values for maximum permissible oxygen concentrations for the dusts used in this work have been determined in other apparatus[3,4] it follows that all the values obtained can be compared in order to investigate the possibility of establishing a standard test, from which realistic values for maximum permissible oxygen concentration can be obtained and applied directly to appropriate industrial plant. The values obtained with the large scale vertical tube and those obtained with the standard furnace[1] and the small scale vertical tube (Hartman type)[3] are given in Table 1.

TABLE 1

Maximum permissible oxygen concentrations as determined in various apparatus

Dust	Diluent gas	Maximum permissible oxygen concentration for prevention of flame propagation - per cent vol		
		Large scale vertical tube	Furnace test at 850°C	Small scale vertical tube
Phenol-formaldehyde resin	Nitrogen	12.6	5.4	11.9*
Phenol-formaldehyde resin	Carbon dioxide	13.8	11.0**	14.0*
Diphenylol propane	Nitrogen	9.3	5.0	9.8*

* Reference 3

** Reference 4

Lower values for maximum permissible oxygen concentrations are given by the furnace than by the other two methods, the greater difference being shown for nitrogen as diluent. Lower values have also been obtained with the furnace in other work[5]. It is likely that the furnace tube, which operates at a temperature of 850°C, constitutes a very large igniting source which preheats the dust cloud before igniting it, a condition not found with many igniting sources in industry.

A comparison between dust explosibility results obtained in the large scale vertical explosion tube and those obtained in a small scale vertical tube apparatus has been reported[2] and maximum permissible oxygen values obtained in both apparatus may be compared from the results given in Table 1. The maximum permissible oxygen concentration values for diphenylol propane as fuel and nitrogen as diluent gas obtained from experiments in the two vertical tubes have been compared and the difference in the values was explained in terms of experimental criteria for flame propagation and representation on graphs[3].

The results obtained in the large scale vertical tube may also be compared with results obtained in a spark tube apparatus as used by the Bureau of Mines, USA and described elsewhere[6]. With this apparatus, in which the combustion tube was 38 mm (1.5 in) diameter and 0.48 m (19 inches) long, and with phenol-formaldehyde resin as fuel and carbon dioxide as diluent gas, the maximum permissible oxygen concentration was found to be 17 per cent by volume[4]. However, in the Fire Research Station large scale vertical explosion tube, with the same oxygen concentration in the atmosphere, flame propagation occurred over the wide dust concentration range of 0.05 g/l to 0.6 g/l (0.05 to 0.6 oz/ft^3) extending throughout the length of the tube for part of that dust concentration range (Fig 6).

This would suggest that explosion test apparatus of such small diameter may indicate apparent safety when a risk of explosion would exist in a furnace or plant of larger dimensions.

It has, however, been shown previously that results obtained in the Fire Research Station large scale vertical explosion tube may be applied to industrial plant of considerably larger proportions[7]. Gas mixture percentages, for use in industrial plant, must incorporate a safety factor, dependent on the accuracy and reliability of the monitoring equipment.

CONCLUSIONS

1. The Fire Research Station large scale vertical tube apparatus can be used to assess the maximum permissible oxygen concentration for the prevention of explosions in dust clouds in a manner directly applicable to industrial plant.

2. The furnace test apparatus, which is the present official test, gives maximum permissible oxygen concentration values which are lower than requisite for safety and impose a severe financial penalty in the supply of large quantities of inert gas.

3. The results obtained in the large scale vertical tube apparatus have been compared with those obtained in a small vertical tube apparatus[3] and were found to be in good agreement and hence results obtained in the small scale apparatus are applicable to large scale plant.

4. The maximum permissible oxygen concentration determined in the Bureau of Mines spark tube apparatus[6], with phenol-formaldehyde resin as fuel and carbon dioxide as diluent gas gave a value which in the large scale vertical tube apparatus permitted explosion propagation throughout the tube length. Hence the application of results, obtained with such a spark tube apparatus, to industrial plant is limited and should be made with caution.

5. The results obtained in the large scale vertical explosion tube have shown there is need for reappraisal of the standard test procedure and apparatus for determining maximum permissible oxygen concentrations so that realistic values may be obtained which are applicable to industrial plant.

ACKNOWLEDGEMENTS

Thanks are due to Mr C F J Berlemont and Mr M Sen who assisted in the experiments.

REFERENCES

1. RAFTERY M M. 'Explosibility Tests for Industrial Dusts' Fire Research Techical Paper No 21 HM Stationery Office, London, 1968.

2. PALMER K N and TONKIN P S. 'The explosibility of Dusts in Small Scale Tests and Large Scale Industrial Plant' Institution of Chemical Engineers Symposium Series No 25 1968.

3. TONKIN P S and FARDELL P J. The determination of maximum permissible oxygen concentration in a small scale vertical tube dust explosion apparatus. FR Note No 928, February 1972.

4. JACOBSON M, NAGY J and COOPER A R. Explosibility of Dusts Used in the Plastics Industry. US Department of the Interior, Bureau of Mines Report of Investigations No 5971, 1962.

5. CRAVEN A D and FOSTER M G. Dust explosion prevention - determination of critical oxygen concentration by vertical tube method. Combustion and Flame Vol 11 No 5, October 1967.

6. DORSETT H G Jr, JACOBSON M, NAGY J and WILLIAMS R P. United States Department of the Interior. Bureau of Mines. Report of Investigations No 5624 - 1960.

7. PALMER K N and TONKIN P S. Coal dust explosions in a large scale vertical tube apparatus. Combustion and Flame 17, 159-170 1971.

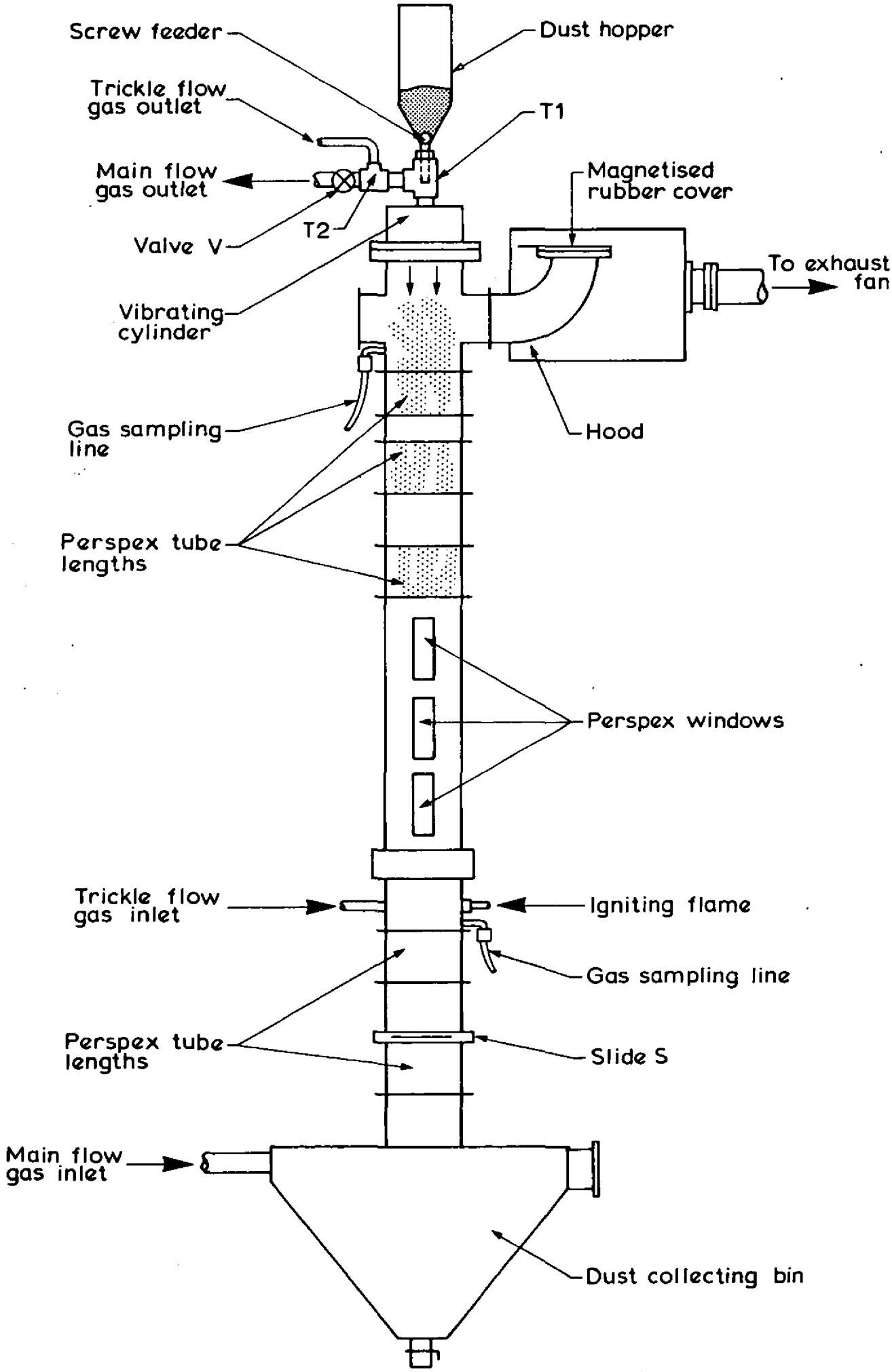

Figure 1 Vertical dust explosion tube apparatus

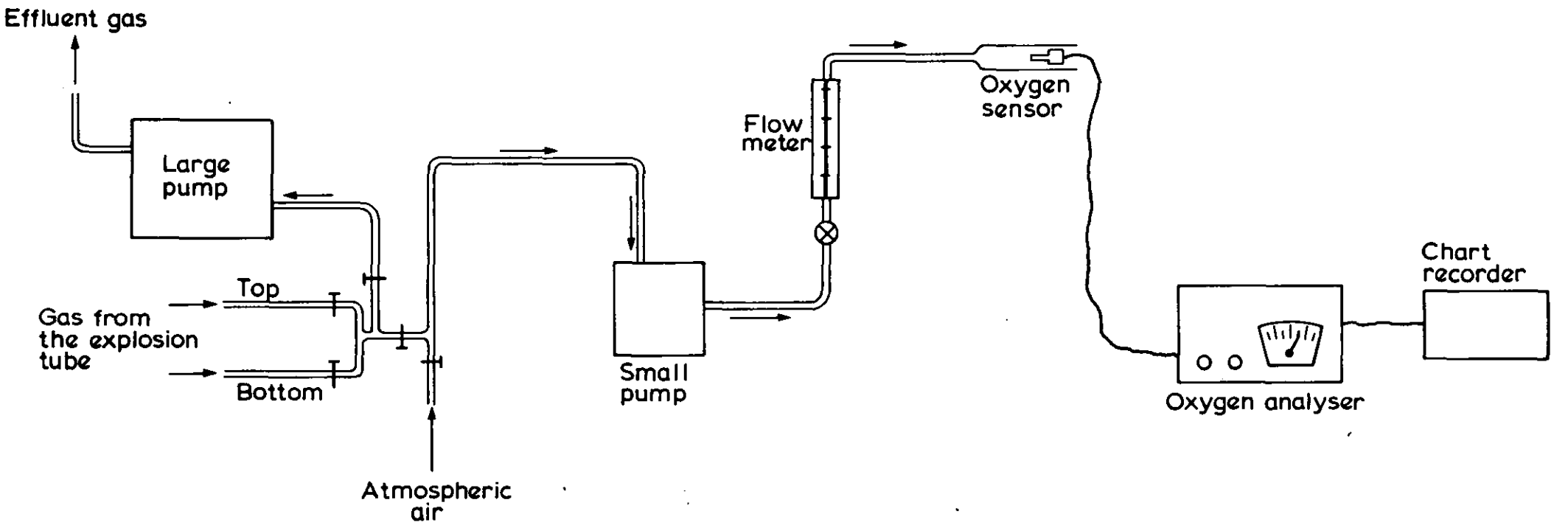

Figure 2 Flow system for sampling and analysing for oxygen, the atmosphere in the large-scale vertical explosion tube

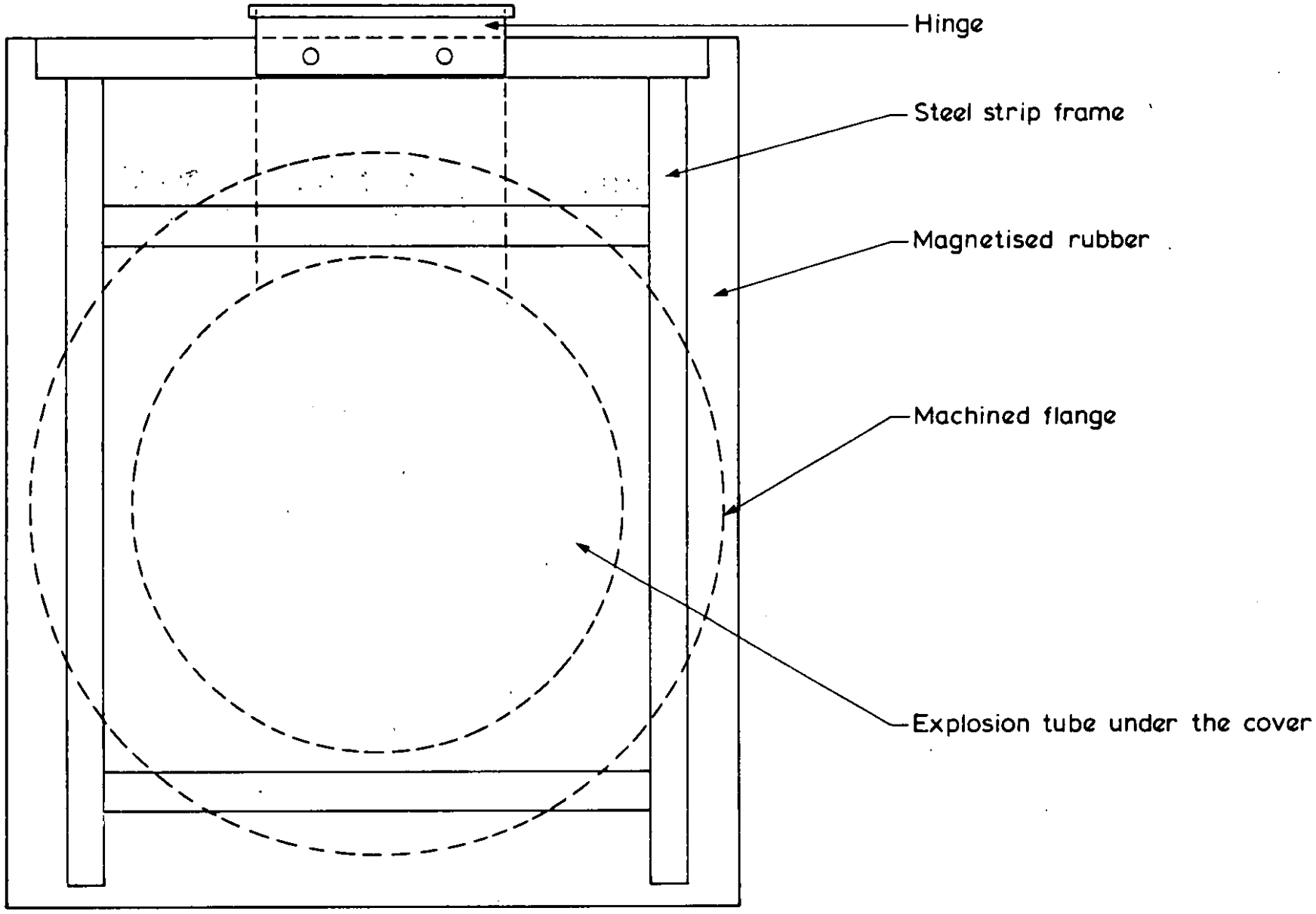

Figure 3 Lightweight magnetised rubber cover as fitted over the top of the explosion tube

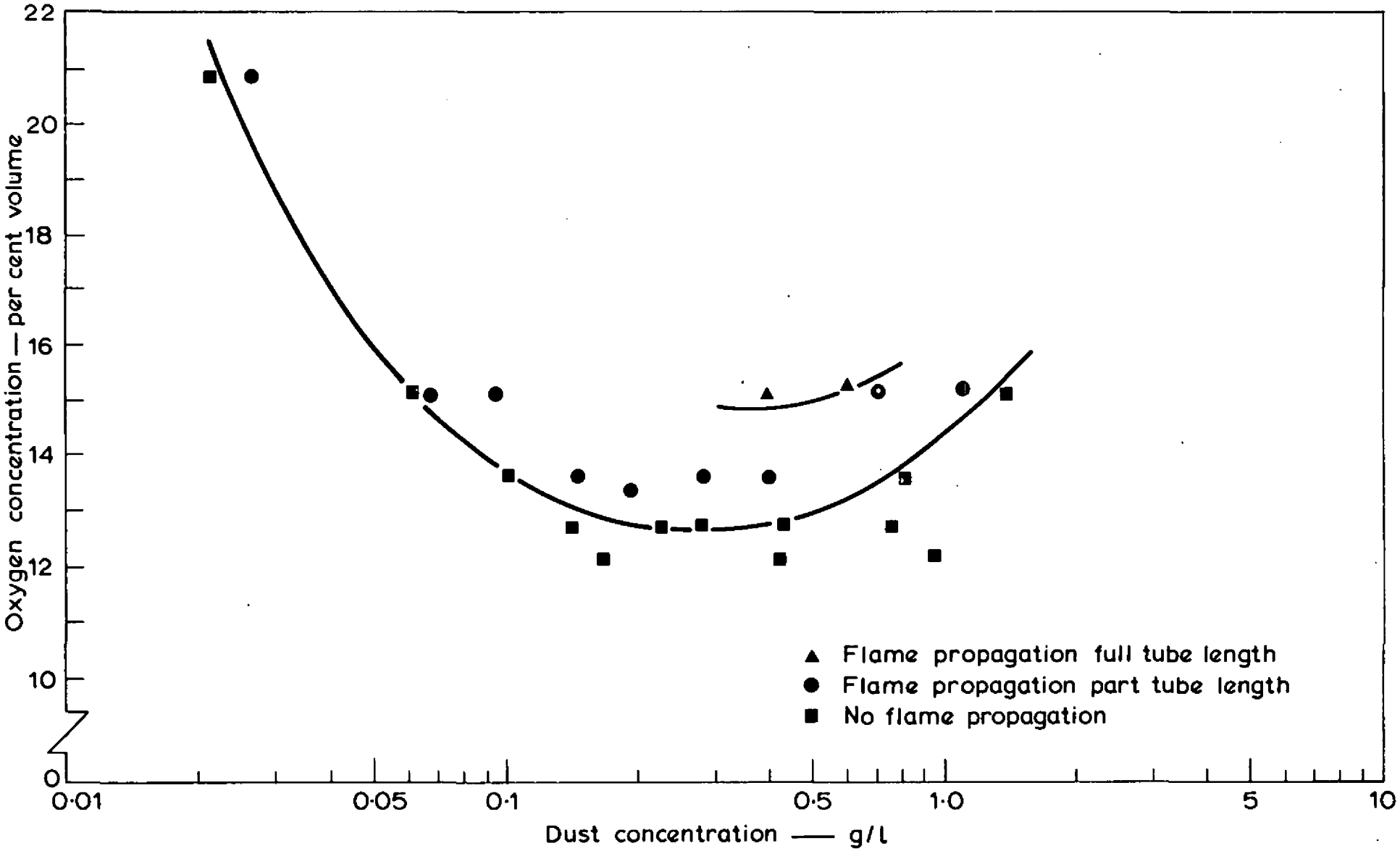

Figure 4 The explosibility of phenol-formaldehyde resin in oxygen-nitrogen mixtures in a large-scale vertical tube apparatus

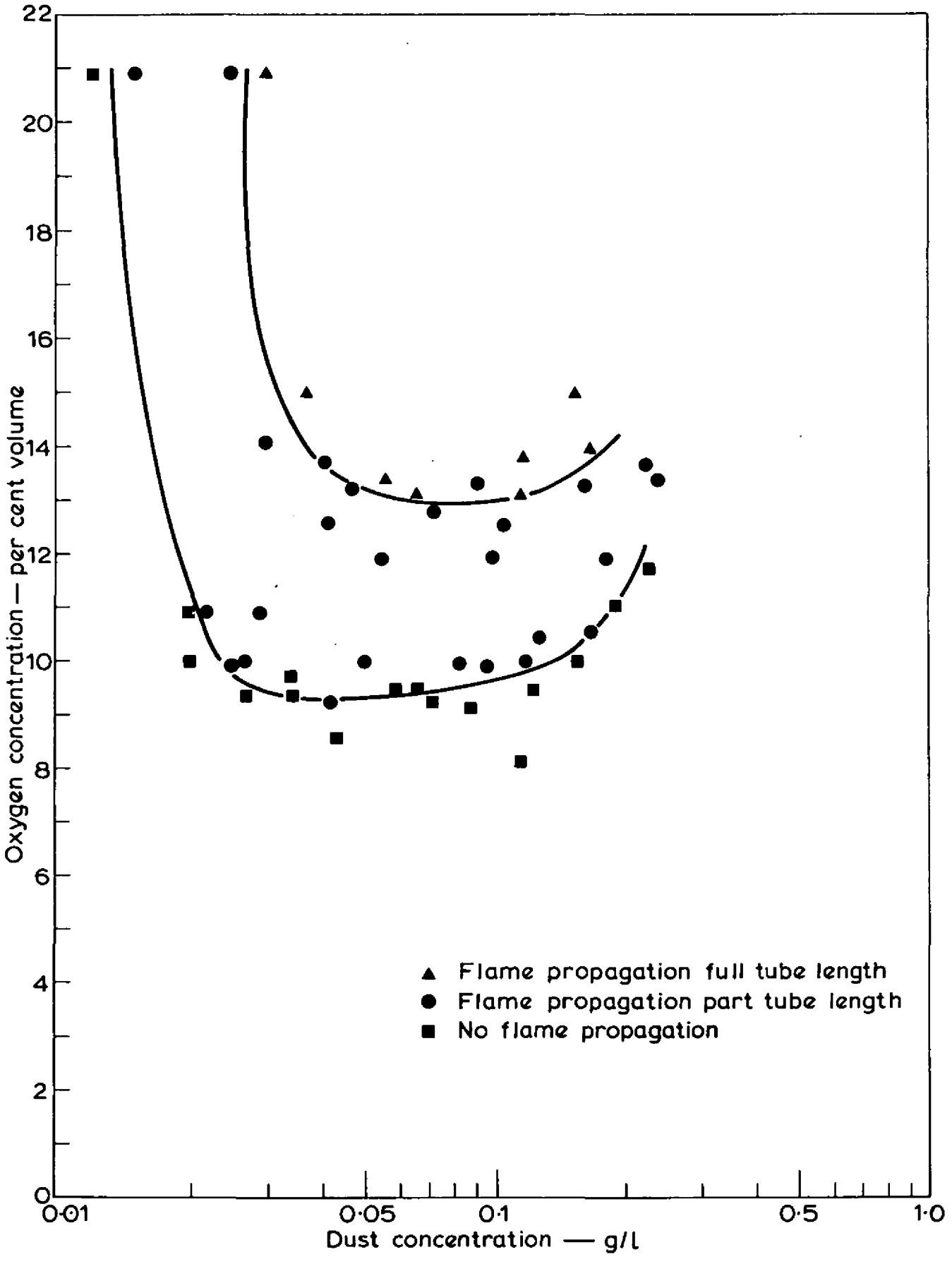

Figure 5 The explosibility of diphenylol propane in nitrogen-oxygen mixtures in a large-scale vertical tube apparatus

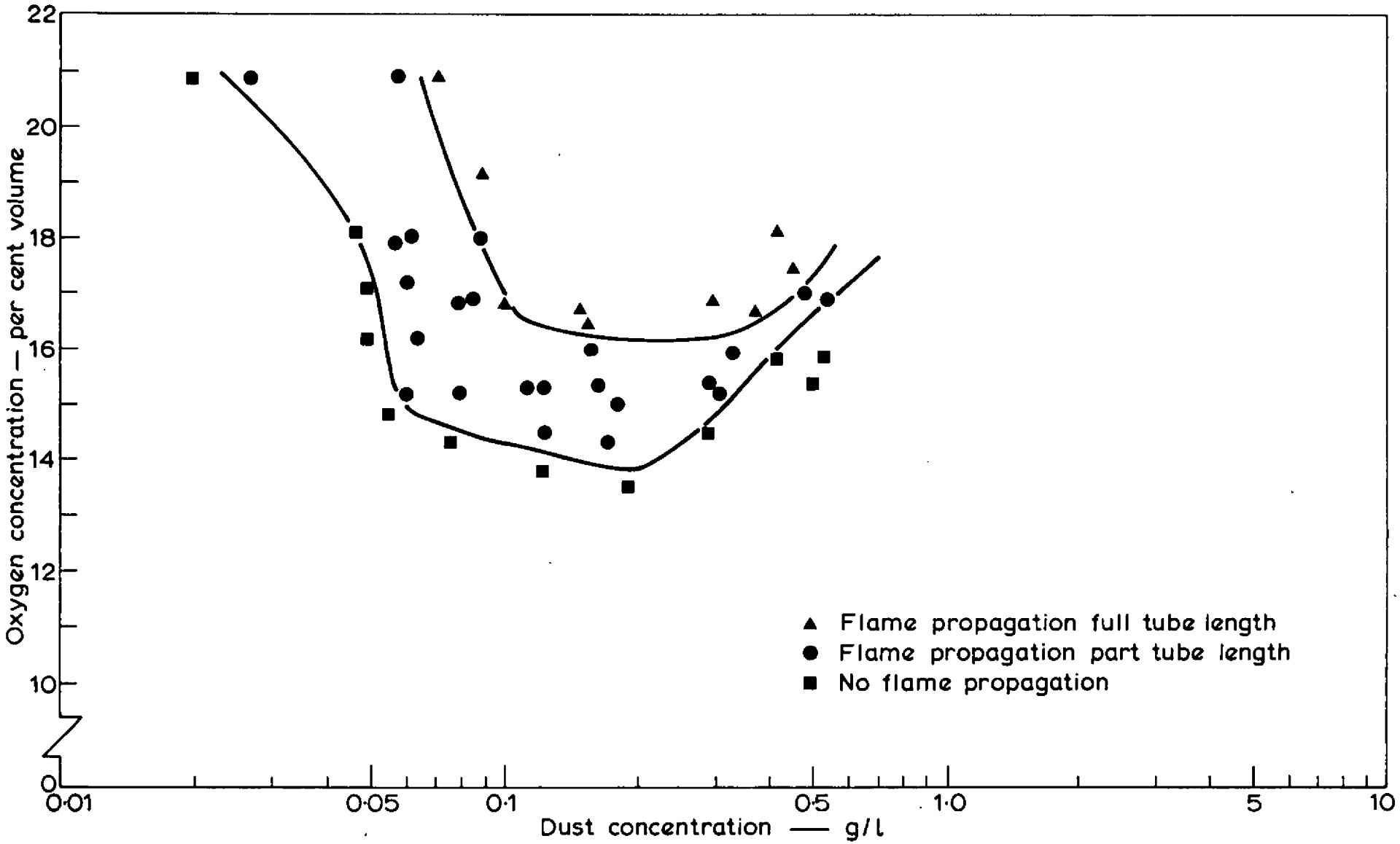

Figure 6 The explosibility of phenol-formaldehyde resin in air-carbon dioxide mixtures in a large-scale vertical tube apparatus

Printed in England for Her Majesty's Stationery Office by Studio Trade Plates Ltd., Watford WD1 8SA 1500 4/75