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THE DETERMINATION OF MAXIMUM PERMISSIBLE
OXYGEN CONCENTRATIONS IN A SMALL SCALE
VERTICAL TUBE DUST EXPLOSION APPARATUS

by

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SUMMARY

A small scale vertical tube apparatus and experimental procedure are described for determining the maximum oxygen concentration permissible to exclude the possibility of an explosion in flammable dust dispersions.

The results obtained with the small-scale apparatus are in good agreement with those obtained in an apparatus of industrial proportions. The results are also compared with those obtained in the standard furnace test apparatus which is at present used for measuring maximum permissible oxygen concentrations for atmospheres in which explosible dusts are dispersed in clouds.

The method of preparing gas mixtures and filling the apparatus has also been used with the standard dust explosion pressure test apparatus.

It is concluded that a test based on the small scale vertical tube apparatus can be used for recommendations for the safe working of industrial plant and would be preferable to the standard furnace test.

KEYWORDS: Dust explosion, prevention, oxygen concentration

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INTRODUCTION

The reduction in oxygen concentration in dust laden atmospheres by the method of dilution with gases such as nitrogen, carbon dioxide and argon in order to prevent dust explosions, is one which can be satisfactorily used in industry as a normal working condition.

The method can be convenient and often more economic than some other methods of combatting dust explosions such as venting or building plant to withstand high pressures. Its use depends upon availability of the inerting gas and the amount of dilution required for safe working.

The standard small scale furnace test¹, which involves a relatively large source of ignition and a heated dust cloud, in current use for measuring maximum permissible oxygen concentration for prevention of dust explosions gives results which, in many cases makes uneconomic the application of the method in industrial plant.

Experiments using apparatus of industrial proportions² have shown that higher levels of oxygen concentration than those indicated by the standard apparatus may be permissible with safety under certain industrial conditions.

In previous work³ the small scale vertical tube standard test apparatus has given explosibility classification results similar to those obtained in a large scale vertical tube. Consequently it was chosen for modification in order to ascertain its suitability as a standard test apparatus for determining realistic maximum permissible oxygen concentration values, which can be directly and economically applicable to industrial plant, when severe sources of ignition are absent.

EXPERIMENTAL

MATERIALS

The following dusts were used in the experiments: phenol-formaldehyde resin, diphenylol propane, caprolactam, protein 1, protein 2, wood, aluminium and magnesium.

They had all been previously classified as being in group (a) for explosibility in the standard dust classification tests¹. In addition, phenol-formaldehyde resin and diphenylol propane had been used in experiments in the large scale vertical tube apparatus in which the maximum permissible oxygen concentration necessary to prevent explosions was determined for both dusts².

APPARATUS

Figures 1 and 2 show, in diagrammatic form, the apparatus used. Plate 1 shows the general experimental arrangement with the protective shield removed from the explosion tube for clarity.

The inert gases and air were mixed in a pressure vessel of 9.1 litres capacity (A Fig.1). The pressure vessel was fitted with hand operated needle valves for separate inlets of inert gas and air and an outlet fitted with a pressure regulator through which the gas flow was maintained for filling the rest of the apparatus. The gas mixing pressure vessel was fitted with a standard test pressure gauge with scale 0-200 p.s.i.g. and sub-divisions of 1 p.s.i.g. The pressure regulator was connected by pipeline to a flow-meter (range 0-1.2 l/min) which in turn was connected to a gas reservoir of 0.46 litres capacity (B Fig.1). A by-pass pipeline was provided so that gas could be supplied to the apparatus without going through the reservoir. The inlet to the reservoir was fitted with a hand operated needle valve and the outlet with a solenoid valve. A needle valve was incorporated in the by-pass pipeline. Suitable pressure tubing connected the reservoir and by-pass to the dispersion cup of the explosion apparatus.

The explosion apparatus was a modification of the small vertical tube apparatus with upward dust dispersion described in detail elsewhere¹, and shown in Fig.2. The explosion tube was 0.31 m (12 in) long and 64 mm (2.5 in) in diameter.

When the igniting source was an electric spark and the explosion tube was of perspex, the modification consisted of an outlet pipe (for the gas mixture) near the top of the explosion tube. When the igniting source was an electrically heated coil the explosion tube was of borosilicate glass fitted at its top with a brass adaptor which permitted closure with a filter paper diaphragm and to which was fitted a gas outlet pipe (Fig.2).

When the igniting source was a continuous electric spark it was provided by a 15 kV high tension mains transformer. The electrically heated coil ignition source was as described elsewhere¹. The temperature of the coil during experiments was adjusted to 1,000°C as indicated by an optical pyrometer.

The oxygen content of the gas mixture was measured by a polarographic method and the values were recorded by a strip chart recorder. Figure 3 shows the method used to bring the gas mixtures to the oxygen analyser sensor from both the gas mixing vessel and the explosion apparatus. The gas mixtures were pumped to the sensor with

a small diaphragm pump.

The gas-mixing apparatus was also used, with the necessary procedural modifications, with the standard dust explosion pressure test apparatus¹ to determine maximum explosion pressure and maximum rate of pressure rise for dusts in a closed vessel with oxygen/inert gas atmospheres.

For the work with phenol-formaldehyde resin and diphenylol propane, dust concentrations were not measured in the small scale vertical tube but weighed quantities of the dusts were placed in the dispersion cup at the beginning of each experiment and the assumption was made that when dispersed the dust would uniformly fill the explosion tube, the concentration thus being calculated in weight per unit volume. Such values were designated 'Nominal dust concentrations' and were used for comparison of maximum permissible oxygen concentration values with those obtained in a large scale apparatus in which dust concentrations were measured in the explosion tube³. For the other dusts used no attempt was made to assess dust concentration in the small scale tube, and the dust was dispersed in accordance with the standard practice¹.

PROCEDURE

The gas mixtures were made up in the mixing vessel by the method of partial pressures. A final pressure in the vessel which would give sufficient gas mixture for the experiment in hand was decided upon and the proportions of each constituent gas were calculated. The amount of inert gas required to raise the pressure in the vessel to the required value was passed into it and the final pressure was then attained by the introduction of air. After the first mixing the gas was discarded and the whole process was repeated. After the third mixing the gases in the vessel were analysed for oxygen. The required value for oxygen concentration, within the accuracy of the gas analyser was usually achieved with the third mixing but if not the whole procedure was repeated as often as was necessary to obtain it.

The dust being tested was placed in the dispersion cup of the explosion apparatus either in weighed or random quantities according to whether or not nominal dust concentrations were required. The gas mixture was allowed to flow through the explosion tube via the gas pressure regulator, the reservoir B and the by-pass (Fig.1).

The flow rate was adjusted to about 500 ml min⁻¹. A low flow rate was used to avoid disturbing the dust in the dispersion cup. The gas emerging from the top of the explosion tube was continuously analysed for its oxygen content.

The dust could be dispersed in one of two ways - either by a sudden release of pressurised gas mixture from the reservoir B, or by a fast continuous stream of gas. For the sudden gas release technique, when the desired oxygen concentration had been achieved, the solenoid valve and by-pass valve were closed and the reservoir B charged to the desired dispersion pressure. After this the flow of gas through the explosion apparatus via the by-pass was resumed, the ignition source was energised, and the solenoid valve opened. When continuous dust dispersion was necessary the reservoir was by-passed, by using the appropriate valves in the system, so that the flow rate of the gas mixture could be varied at will by use of a hand operated valve to disperse the dust and to maintain the dust cloud around and above the igniting source. With both methods of dispersion observation was made as to whether or not flame propagated away from the source of ignition, and if so the distance the flame propagated up the tube was noted. These two methods of dispersion were employed because in standard classification tests a variety of dispersion methods is sometimes necessary before a self-propagating flame is obtained.

If no explosion occurred at the first attempt further attempts were made under the same conditions. If necessary, additional attempts were made to explode the dust using both methods of dispersion, varying the quantity of dust to be dispersed, varying the pressure of the dispersing air in the reservoir and, in the case of electric spark ignition source, varying the gap between the electrodes.

RESULTS

Figures 4, 5 and 6 are plots of the results from experiments in the large scale vertical tube and the small scale vertical tube in which phenol-formaldehyde resin was the fuel and nitrogen the inert gas. Each point on the graphs represents a group of three tests in the apparatus and where the extent of flame propagation varied within a group the point shown indicates the most extensive flame propagation.

Figures 7 and 8 are similar plots for the experiments in which diphenylol propane was the fuel and nitrogen the inert gas.

Figures 9, 10 and 11 show the curves obtained when carbon dioxide was the inert gas and phenol-formaldehyde resin was the fuel.

In Figs 4 to 11 inclusive distinction is made as to whether flame propagated away from the igniting source for the full length of the combustion tube, part tube length or not at all.

Table 1 gives the lowest maximum permissible oxygen values from the experiments carried out in the small scale vertical tube apparatus and the corresponding values obtained in the large scale vertical tube experiments and the standard furnace test for some of the dusts. Nitrogen was the inert gas used in all the experiments.

Table 1
Maximum permissible oxygen determinations

Dust	Maximum permissible oxygen concentration (per cent vol. using nitrogen as inert gas)		
	Small scale vertical tube	Large scale vertical tube	Furnace
Phenol-formaldehyde resin	11.9	12.6	5.4
Diphenylol propane	9.8	9.3	5
Caprolactam	11.4	-	8
Protein 1	12.9	-	5.5
Protein 2	12.9	-	5.5
Wood	12.5	-	5.0
Aluminium	12.3	-	12.0
Magnesium	2.5	-	-

When related tests were carried out in the standard pressure test apparatus with magnesium dust in atmospheres with oxygen content reduced from the atmospheric value by dilution with inert gases the maximum permissible oxygen value was greater and the explosion pressures lower with oxygen/nitrogen mixtures than with air/argon or oxygen/argon mixtures.

For the tests in the small scale tubes the oxygen concentration values obtained from the analyser did not vary by more than ± 2.0 per cent from the values calculated from the gas mixing data (e.g. 10.0 ± 0.2).

DISCUSSION

Since the object of the work was to investigate the possibility of establishing a small scale vertical tube standard test to determine maximum permissible oxygen concentration in which dust explosions will not occur and give results which can be directly and economically applicable to appropriate industrial plant, it was necessary for the results obtained to be compared with those obtained in the furnace test¹ and the large scale vertical tube².

In the standard small scale vertical tube classification test the criterion for explosion was whether or not flame in the dust cloud detached itself from the igniting source¹. With the present results obtained with the small scale vertical tube, distinction is made between flames propagating full tube length, those propagating part tube length and no propagation at all (i.e. no flame detached from the igniting source). In the large scale vertical tube similar distinctions were made but flame propagating less than 0.61 m (2 ft) was considered to be under the influence of the igniting source and was not considered to be self supporting. Such flames are recorded as non-propagating on the relevant graphs.

In the small scale vertical tube apparatus there were differences between the results obtained with each igniting source.

Figures 4 to 11 show that there are considerable differences between the values of the oxygen concentrations at which full tube length propagation took place in the small scale vertical tube apparatus and the values for similar propagation in the large scale vertical explosion tube. There was, however, reasonable agreement between the oxygen values, obtained in both apparatus at which no propagation of flame occurred. These values have been taken to constitute the maximum permissible oxygen concentration for prevention of explosions.

Flame propagation for part tube length obtained with the small scale vertical tube apparatus showed that the criterion for explosion as defined above is correct for application of the results to large scale plant since such flame propagation corresponds to that obtained in the large scale explosion tube. It is known that significant explosion pressure values can be obtained with dusts which give partial propagations in the large scale vertical tube³.

The dust concentrations at which the maximum permissible oxygen values occurred differ in the large and small scale apparatus and this may be attributed to the different methods of determining dust concentration in the two apparatus as described above.

The work carried out in the standard pressure test apparatus¹ with magnesium dust showed that the method of making the oxygen/inert gas mixtures, used with the small vertical tube test apparatus, was readily adaptable to the pressure test procedure. Consequently, the method is now used as routine when it is required to measure maximum explosion pressure and rate of pressure rise for explosible dusts in atmospheres with oxygen content different from that in air.

The results in Table 1 show that for all dusts other than metal dusts, the values for maximum permissible oxygen content are much lower when determined in the furnace test. Other workers have also found this to be the case⁴. The furnace test, as described previously¹ incorporates a large source of ignition which operates in the dual capacity of heating the dust cloud to a relatively high temperature and igniting it. For the majority of industrial dust handling systems and processes where such ignition sources do not exist, the furnace test gives oxygen values which are low and unrealistic and not economically applicable.

The difference between the two values for maximum permissible oxygen for diphenylol propane in vertical tubes shown in Table 1 may be accounted for by reference to Fig.7. The lowest point for partial propagation represents one partial propagation in three experiments, the other two experiments produced non-propagation. The point represents the worst conditions in the group of three experiments as explained above. In the one partial propagation, i.e. propagation in excess of 0.61 m (2 ft) from the igniting source, the distance above the demarcation mark that the flame reached before self-extinction was so slight as to be designated and recorded as '0.61 m plus (2 ft plus)'. Figure 7 shows that this accounts for most of the difference between the values obtained in the large and small scale apparatus. In the application of such results to industrial plant the value for oxygen concentration used in the plant would ensure a safety margin which would automatically take such relatively small differences into account.

In all cases with both nitrogen and carbon dioxide as the diluent gases the lowest values for maximum permissible oxygen content, obtained in the small scale apparatus, may be considered to agree sufficiently well with those obtained in the large scale vertical tube to be used as a basis for the application of oxygen levels in industrial plant that will ensure safe and economic working.

CONCLUSIONS

1. The small scale vertical tube explosion apparatus can be used to determine maximum permissible oxygen concentration to prevent dust explosions.
2. Results obtained in the small scale vertical tube apparatus were in reasonable agreement with those obtained in the large scale vertical tube apparatus when phenol-formaldehyde resin and diphenylol propane were the explosible dusts and nitrogen and carbon dioxide were the inerting gases.

3. It was found necessary to use both types of ignition source in the small scale vertical tube apparatus to obtain results in agreement with those obtained in the large scale vertical tube apparatus.
4. It has been shown that the values for maximum permissible oxygen concentration as determined in the furnace test are unnecessarily low when considered for application to many industrial situations in which large sources of ignition are absent.
5. The method of obtaining oxygen/inert gas mixtures has been used successfully with the standard test apparatus¹ for measuring maximum pressure and rate of pressure rise with explosible dusts in reduced oxygen atmospheres.
6. The results obtained in the small scale vertical tube apparatus may be used as a basis for determining oxygen levels in industrial plant that will ensure safe and economic working.

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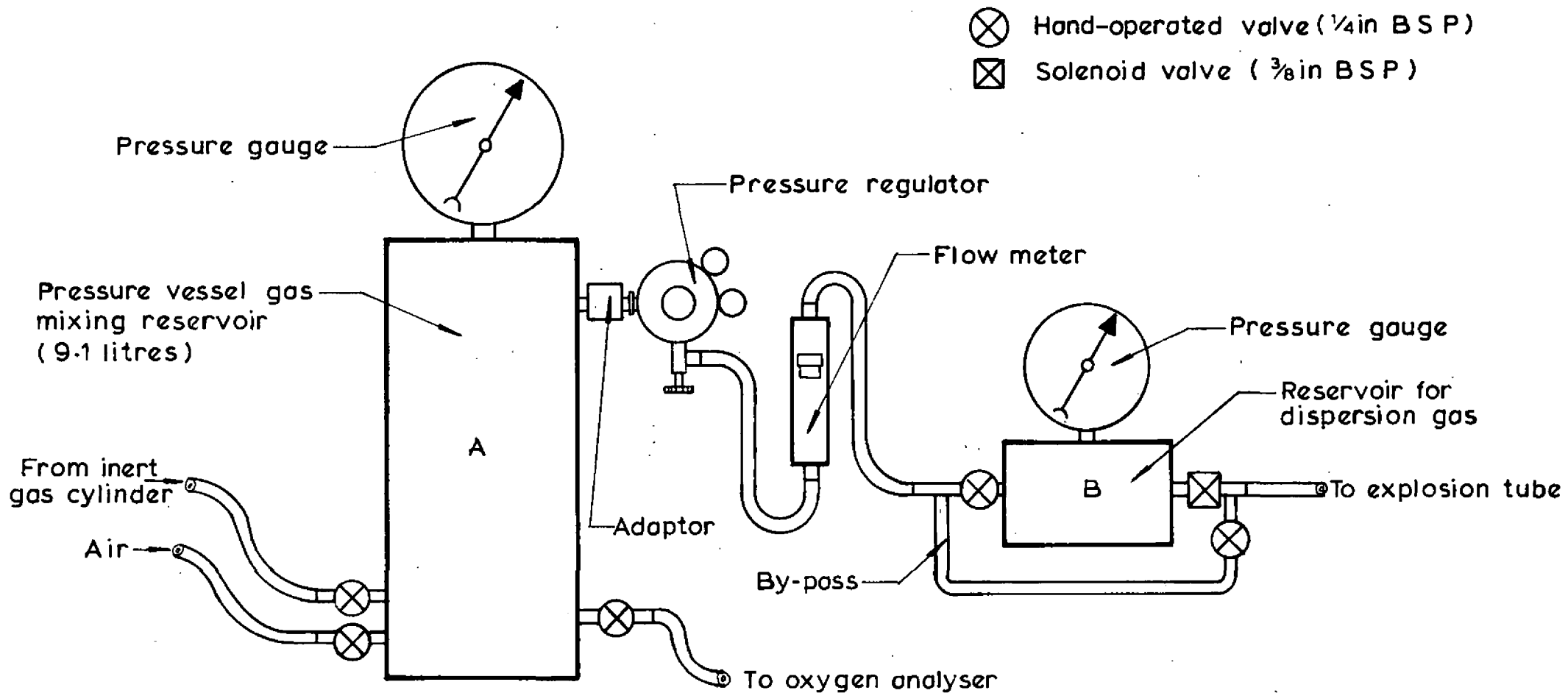


FIG.1 GAS MIXING AND SUPPLY APPARATUS

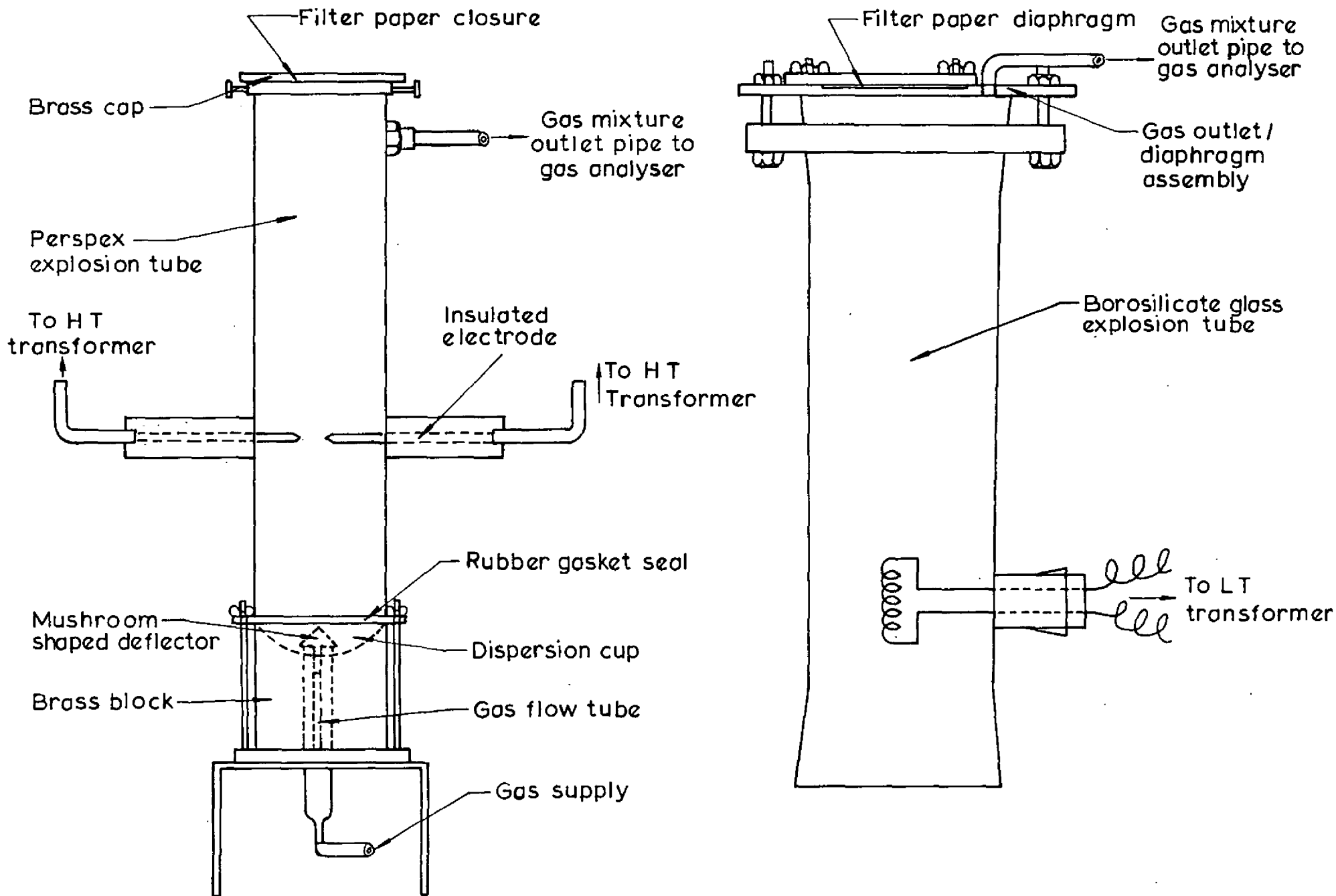


FIG.2 DISPERSION CUP AND EXPLOSION TUBES

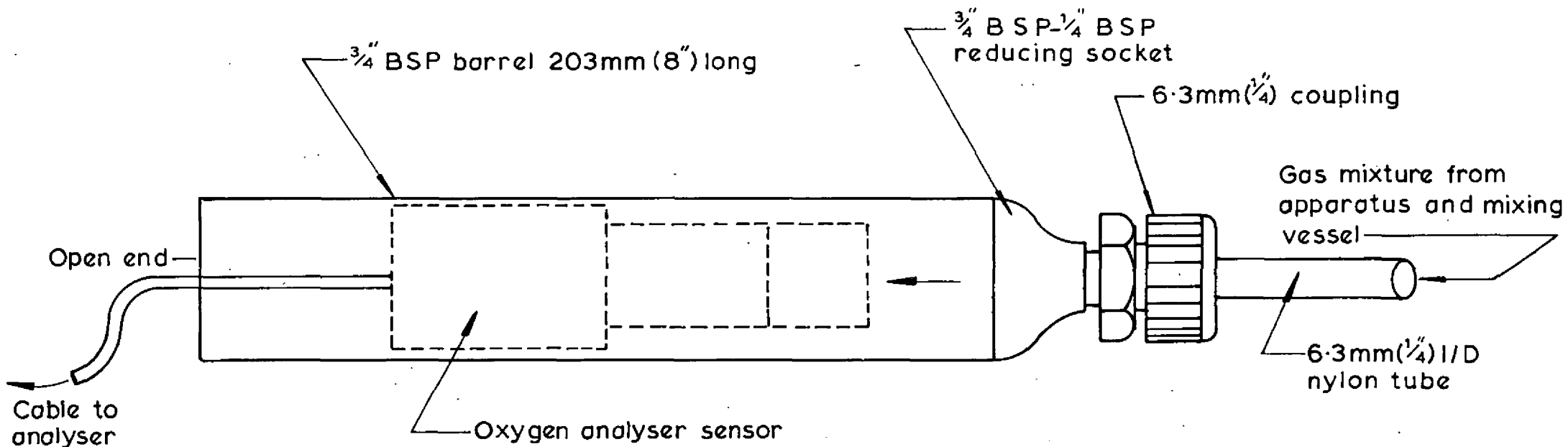


FIG. 3 METHOD OF PASSING GAS MIXTURE OVER THE OXYGEN ANALYER SENSOR

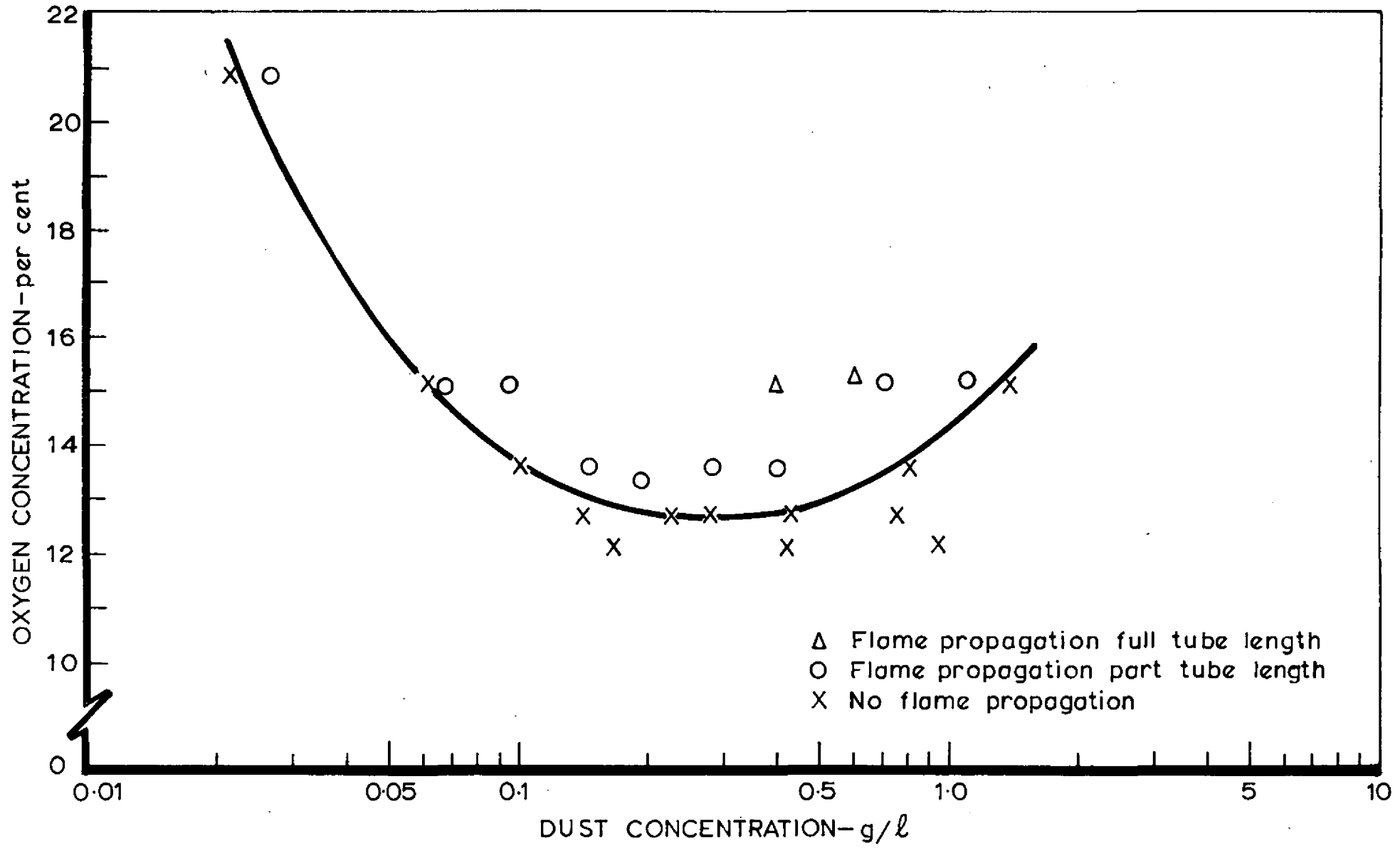


FIG.4 THE EXPLOSIBILITY OF PHENOL-FORMALDEHYDE RESIN IN OXYGEN - NITROGEN MIXTURES IN A LARGE-SCALE VERTICAL TUBE APPARATUS

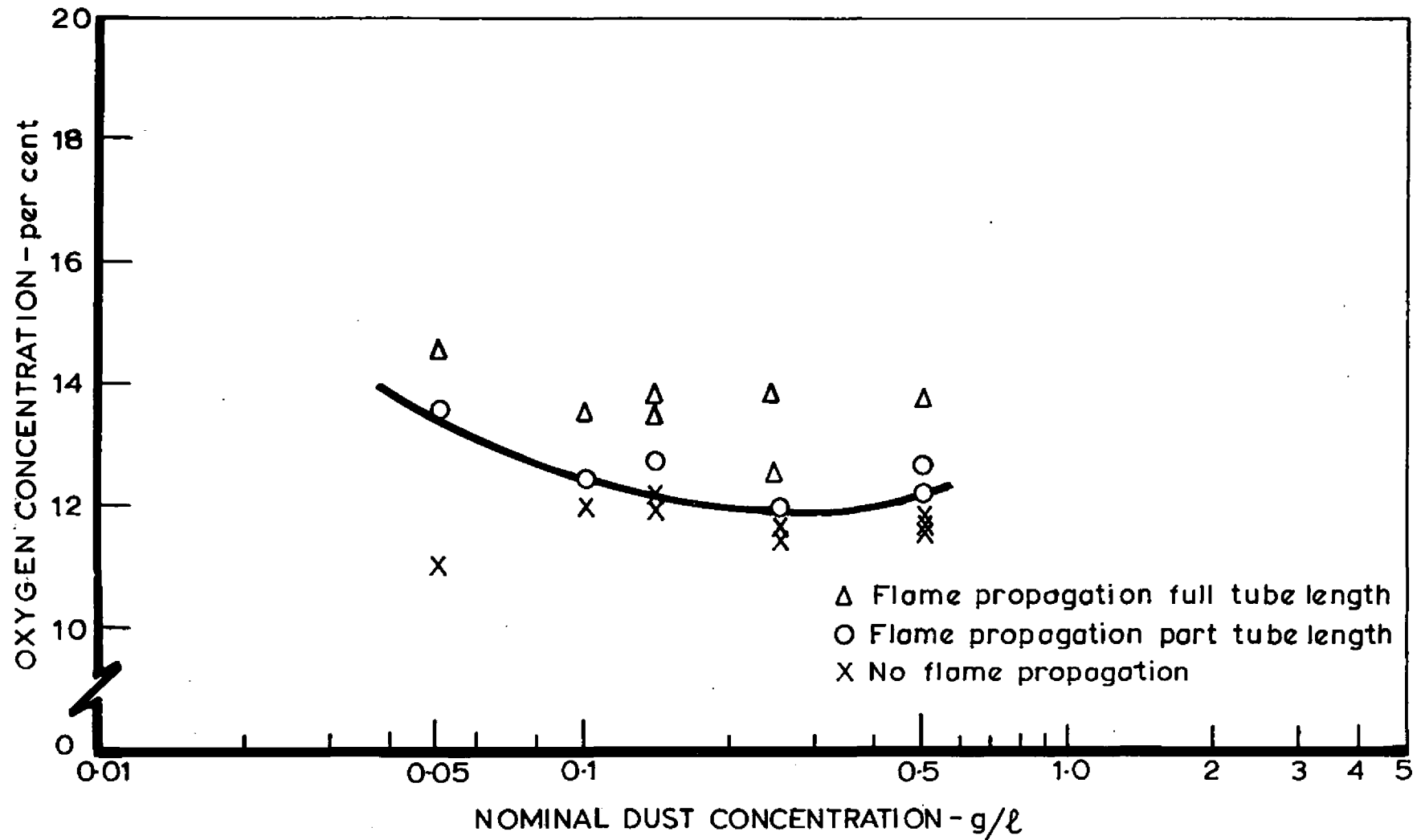


FIG.5 THE EXPLOSIBILITY OF PHENOL-FORMALDEHYDE RESIN IN OXYGEN-NITROGEN MIXTURES IN A SMALL-SCALE VERTICAL TUBE WITH COIL IGNITION

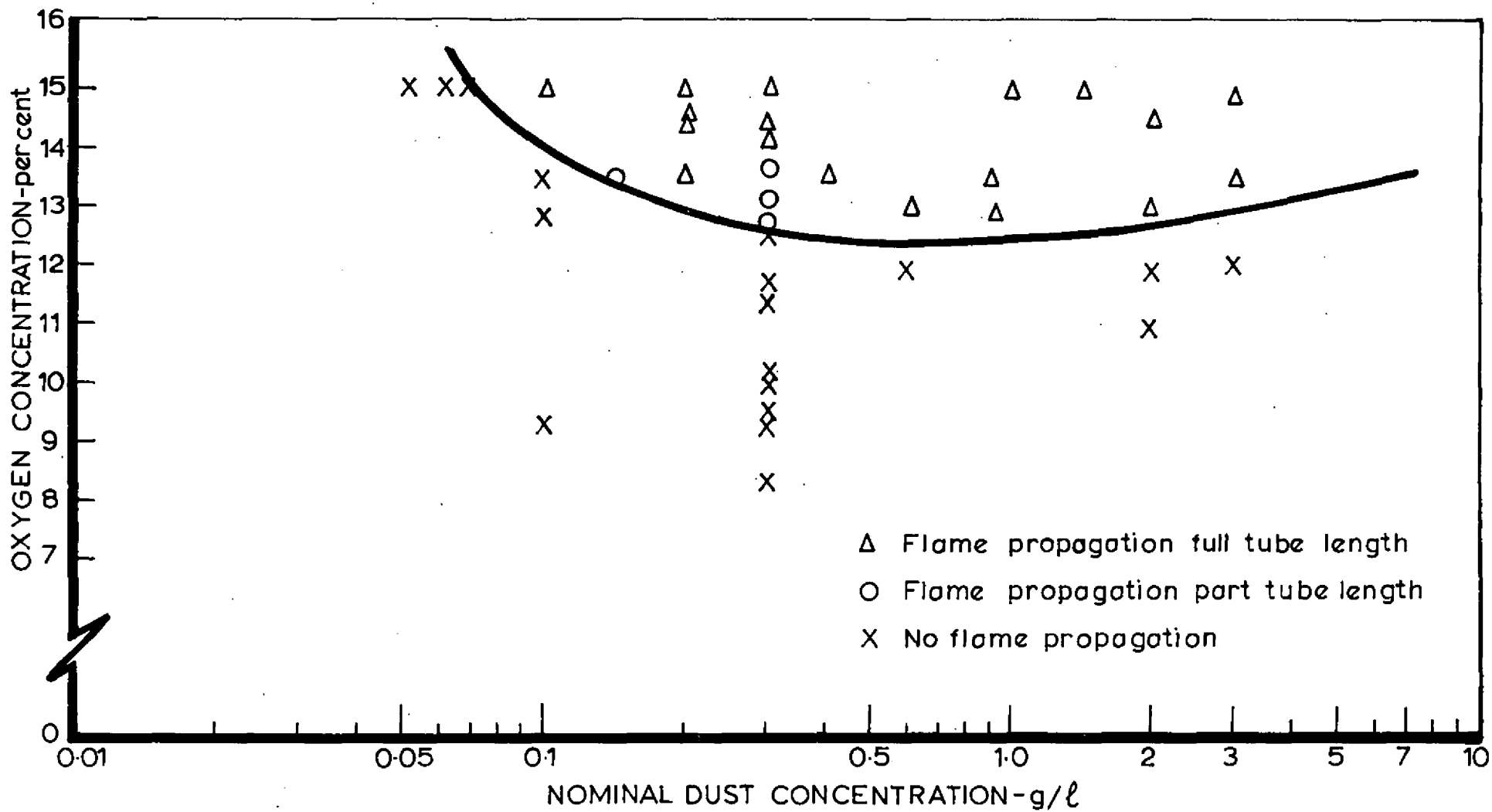


FIG.6 THE EXPLOSIBILITY OF PHENOL-FORMALDEHYDE RESIN IN OXYGEN-NITROGEN MIXTURES IN A SMALL-SCALE VERTICAL TUBE APPARATUS WITH SPARK IGNITION

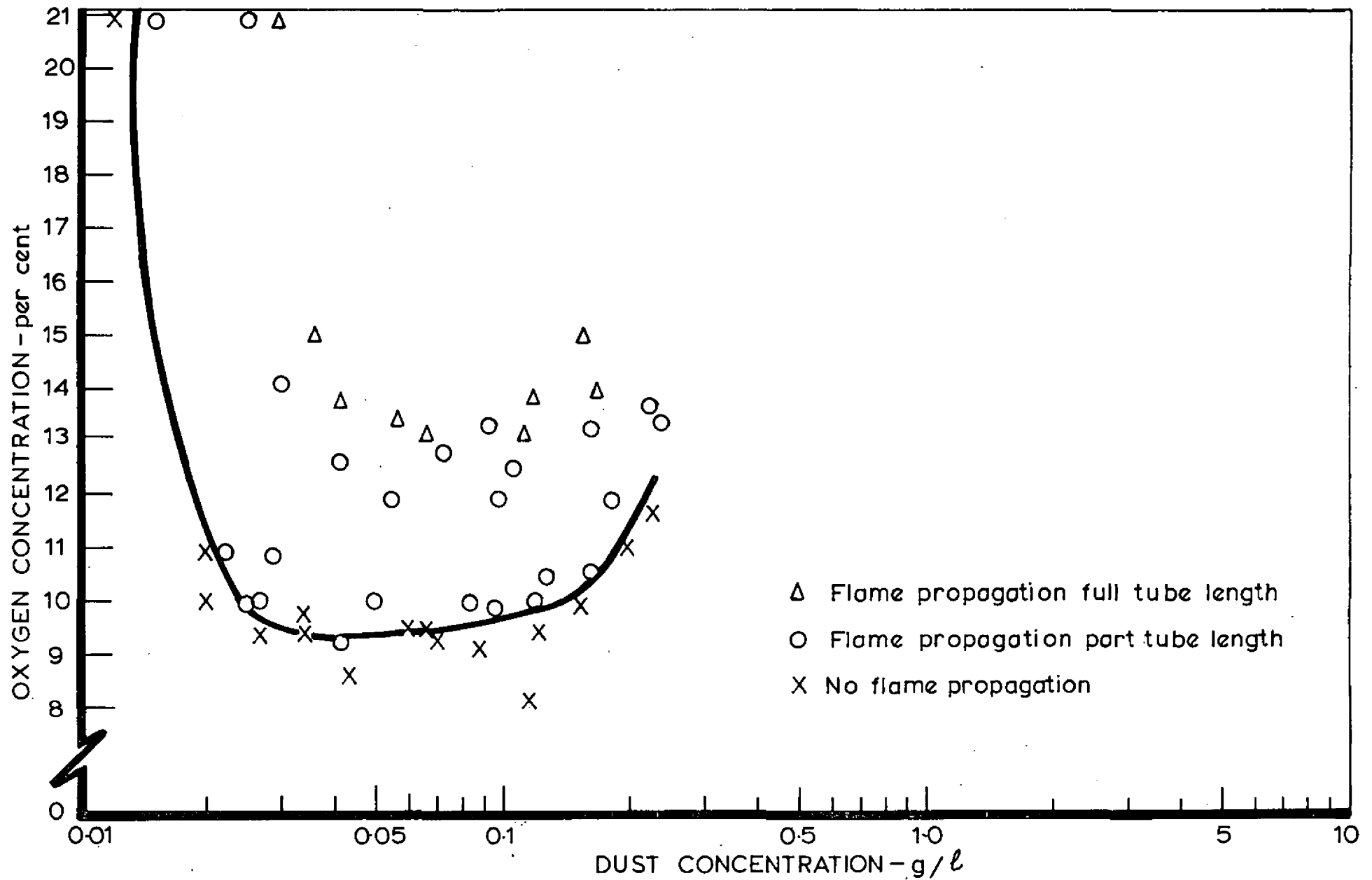


FIG.7 THE EXPLOSIBILITY OF DIPHENYLOL PROPANE IN OXYGEN-NITROGEN MIXTURES IN A LARGE-SCALE VERTICAL TUBE

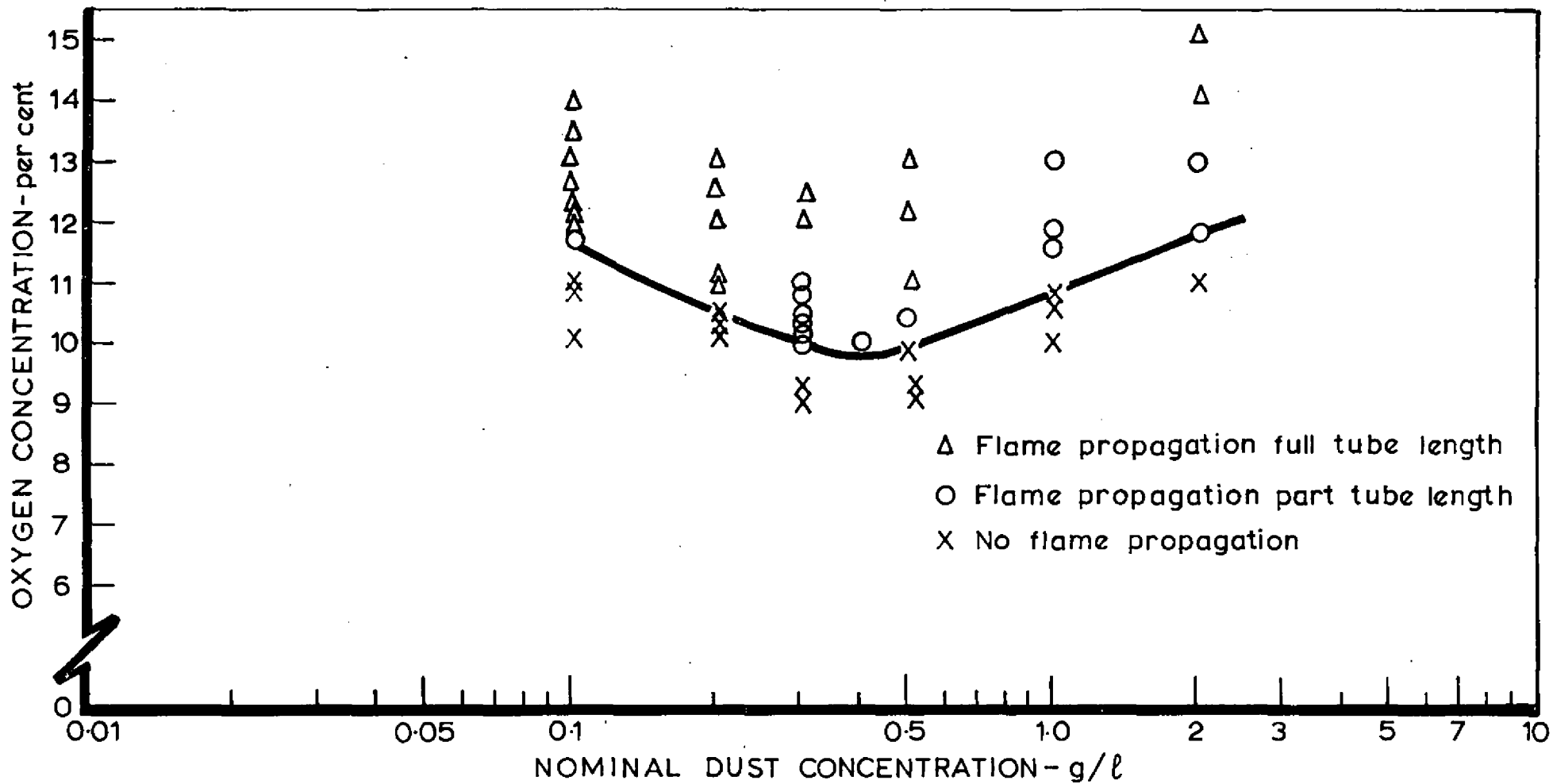


FIG.8 THE EXPLOSIBILITY OF DIPHENYLOL PROPANE IN OXYGEN-NITROGEN MIXTURES IN A SMALL-SCALE VERTICAL TUBE WITH SPARK IGNITION

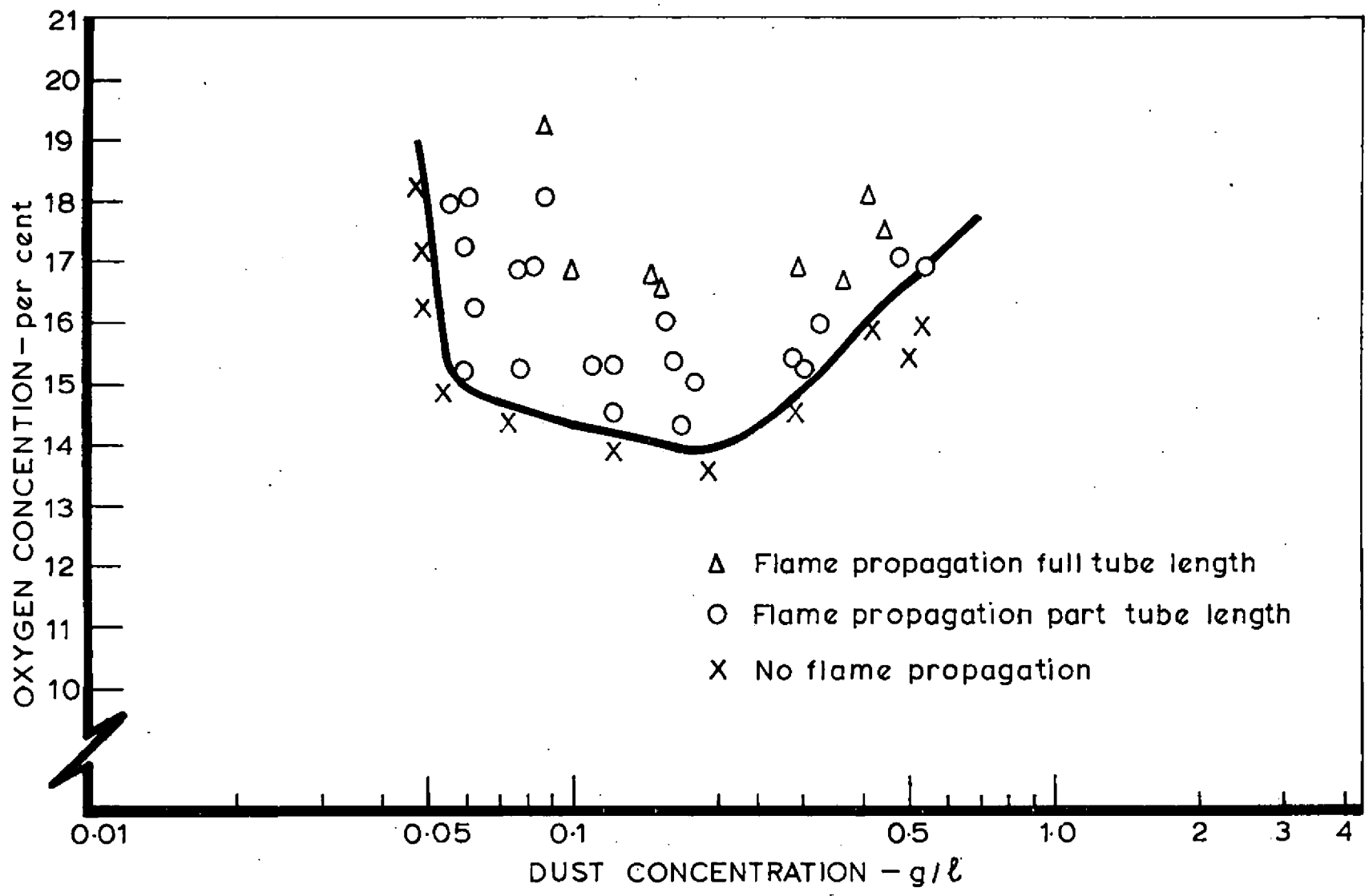


FIG.9 THE EXPLOSIBILITY OF PHENOL-FORMALDEHYDE RESIN IN AIR/ CARBON DIOXIDE MIXTURES IN A LARGE-SCALE VERTICAL TUBE

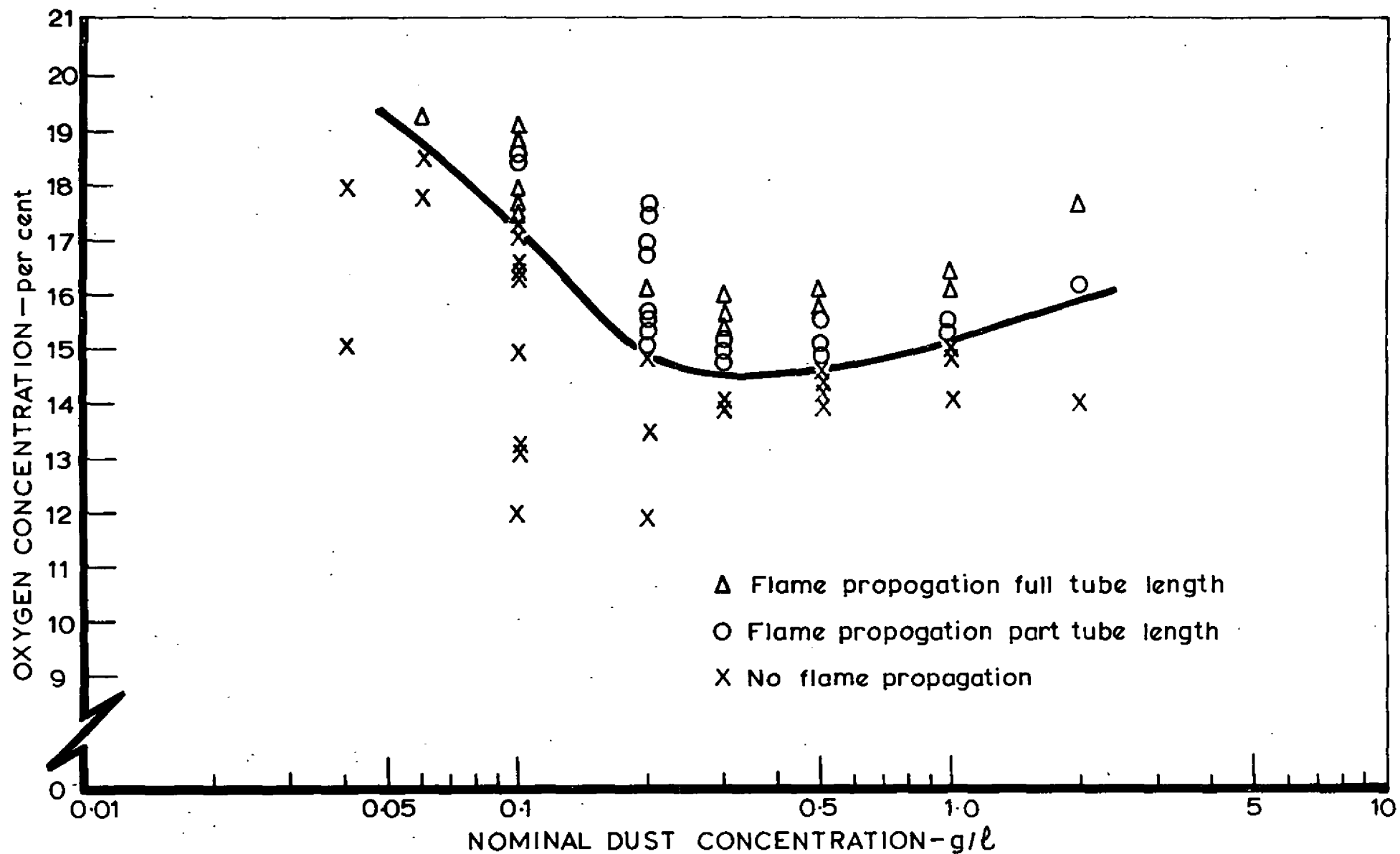


FIG.10 THE EXPLOSIBILITY OF PHENOL-FORMALDEHYDE RESIN AIR/CARBON DIOXIDE MIXTURES IN SMALL-SCALE VERTICAL TUBE APPARATUS WITH SPARK IGNITION

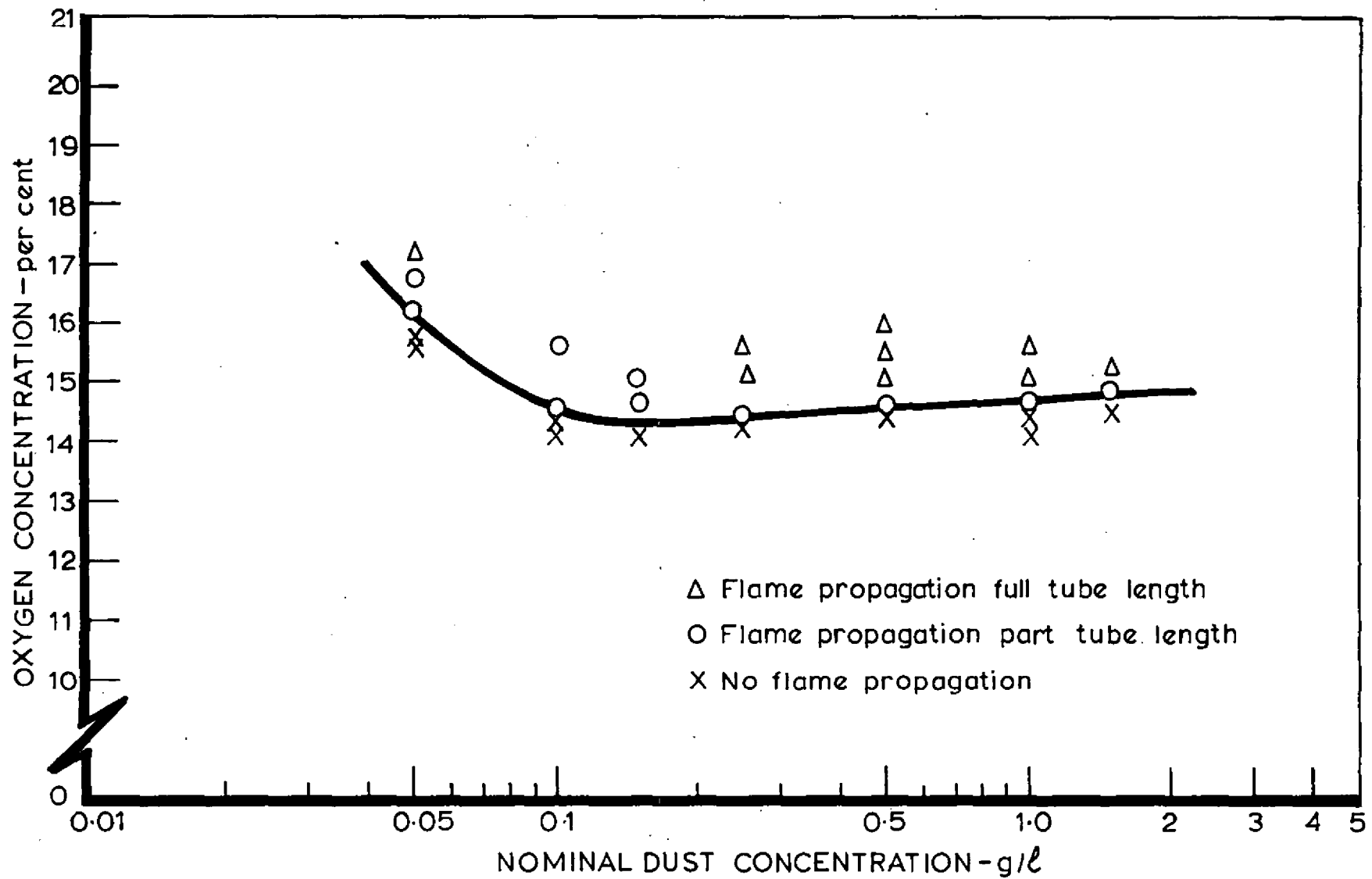
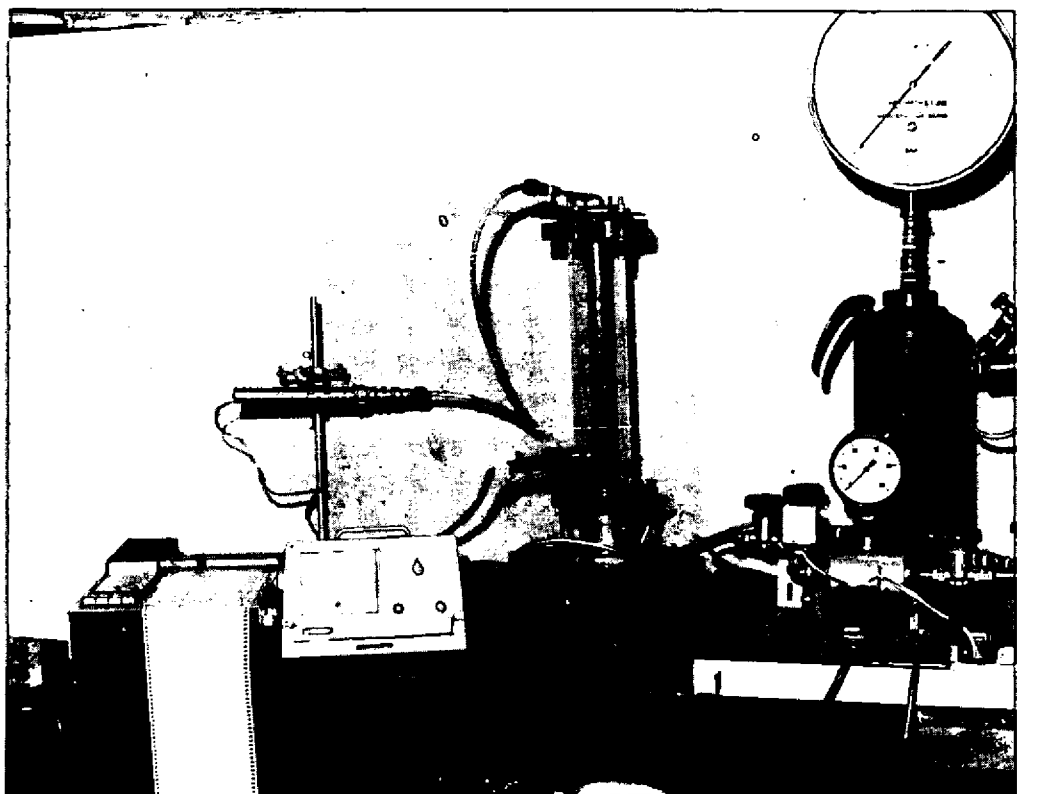


FIG.11 THE EXPLOSIBILITY OF PHENOL-FORMALDEHYDE RESIN IN AIR/CARBON DIOXIDE MIXTURES IN A SMALL-SCALE VERTICAL TUBE APPARATUS WITH COIL IGNITION



THE SMALL SCALE VERTICAL EXPLOSION TUBE WITH
GAS MIXING APPARATUS AND OXYGEN ANALYSER

PLATE 1

