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THE EXPLOSIBILITY OF SOME INDUSTRIAL DUSTS IN A LARGE SCALE CYCLONE PLANT

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SUMMARY

The explosibility of some industrial dusts in a cyclone plant has been investigated. The dusts were dispersed in the turbulent air stream and ignited with a propane flame.

All the dusts which propagated explosions in the plant were in explosibility Class I. Manioc, a marginal Class I dust, and calcium citrate, a Class II dust, did not explode. Preliminary information has been obtained on the size of vents to safely relieve explosion pressures in the cyclone itself.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

For many years cyclones have been used in industry for the separation of solids from gases. When the solid particles are those of an explosible dust and the gas phase is a supporter of combustion an explosion and fire hazard exists. Ninety-two fires were reported in cyclones in the United Kingdom during 1964.[1]

For adequate but economic precautions it is necessary to assess the extent of the explosion hazard in the turbulent conditions of cyclone plant. In order to do so experimental work has been carried out using a cyclone plant of industrial scale to investigate the relationship between explosibility Class, as determined in the standard test apparatus[2] and the ability of dusts to propagate explosion in the cyclone. The cyclone plant was modified for experimental purposes to allow continuous circulation of air and dust.

The results of the standard tests are used to classify the dusts as follows:-

Class I. Dusts which ignite and propagate flame readily, the source of heat required for ignition being small.

Class II. Dusts which ignite readily with flame but require a larger source of ignition.

Class III. Dusts which do not ignite in the tests.

In the present work with the cyclone plant dusts have been used which were vigorously or marginally Class I, or were Class II.

In industry dust handling plant often incorporates rotary valves as explosion checks and provision may be made for the venting of explosions. This report gives preliminary information on the observed performance of rotary valves as explosion checks and on venting areas required to keep the explosion pressure in the plant at low values.

EXPERIMENTAL

Materials

All the dusts were commercial grades as marketed by the manufacturers and used in industry. They were classified for explosibility in the standard test apparatus.

The phenolformaldehyde resin was the same as described previously[3] with a mean particle diameter of 15 microns. Analyses of the other dusts used are given in Table 1 in terms of B.S. sieve sizes, and moisture contents are given in Table 2.

Table 1

Sizing analyses of the dusts

Dust	Explosibility Classification	Per cent weight				
		+ 60 mesh	- 60 + 72 mesh	- 72 + 120 mesh	- 120 + 240 mesh	- 240 mesh
Cork	I	18.4	11.6	22.4	18.0	26.4
Manioc	I (Marginal)	3.9	27.9	41.9	24.4	1.9
Urea formaldehyde resin	I	0.2	2.3	4.8	32.3	59.5
Calcium citrate	II	13.8	8.0	50.1	20.9	7.2

Table 2

Moisture content of the dusts

Dust	Moisture content per cent
Phenol formaldehyde resin	4.1
Cork	10.6
Manioc	14.1
Urea formaldehyde resin	7.8
Calcium citrate	11.2

Apparatus

Cyclone plant.

The plant consisted of a number of functional items all connected to form closed circuits for both the air stream and the conveyance of dust. Figure 1 is a diagram of the plant.

The cyclone was constructed of 0.3 cm (0.125 in) thick mild steel plate, was 1.9 m (6.25 ft) in height, 2.44 m (8 ft) diameter at the top and had an outlet at the bottom 19.3 cm (7.6 in) in diameter.

The inlet of the cyclone was connected to a fan of approximately 0.9 m (3 ft) diameter, by means of steel flanged ducting of internal diameter 29.9 cm (11.75 in), 1.8 m (6 ft) length of which was horizontal and the remaining 3.5 m (11.5 ft) was vertical. The outlet at the bottom of the cyclone was connected to a six bladed rotary valve which returned the dust, extracted by the cyclone, to the dust hopper which was of 0.3 m^3 (10 ft^3) capacity. The air outlet at the top of the cyclone was a pipe 29.9 cm (11.75 in) internal diameter situated in the centre of a 61 cm (24 in) outside diameter annulus of 6.4 mm (0.25 in) thick mild steel plate. The outlet pipe extended into the cyclone 45.8 cm (18 in) and was joined to an outlet scroll outside. The scroll was connected to the intake side of the fan by ducting of internal diameter 29.9 cm (11.75 in), a 92 cm (3 ft) length of which was horizontal and the remaining 4 m (13 ft) length was vertical. In the top of the scroll there was a 39 cm (15.4 in) diameter hole which could either be covered with a steel plate or used as a vent. Another six bladed rotary valve at the bottom of the hopper delivered dust into the return air stream for re-circulation. A deflector was fitted at the bottom of the return air duct to direct the airstream beneath the outlet from the rotary valve to ensure good mixing of dust and air. The ducting connecting with the fan inlet constituted a mixing chamber for the dust and air and it was fitted with a vent of area 0.18 m^2 (1.9 ft^2). A sliding air intake regulator was fitted in the ducting on the inlet side of the fan (Z Fig. 1).

The top of the cyclone was divided into six sector vents each of area 0.12 m^2 (1.3 ft^2) which could be covered with metal plates or bursting materials. Figure 2 shows the vents at the top of the cyclone.

The cyclone and lengths of ducting were fitted with inlet bosses which were tapped 2 inch B.S.P., suitable for accommodating flame detectors and pressure measuring devices.

A 7 H.P. 3 phase, electric motor powered the fan through a "Vee" belt drive.

The rotary valves were operated by 0.5 H.P. electric motors through fixed ratio gearing systems. Limited variation in the dust feed could be made by inserting a plate between the bottom of the hopper and the top of the rotary valve and also by varying the amount of dust placed in the hopper.

To allow access to all parts of the plant staging was erected around it at two levels, 1.8 m (6 ft) and 4.3 m (14 ft) from the ground. The whole plant was situated in a steel framed, galvanised iron cladded building, part of the roof of which could be opened during experiments. Sliding doors on one side of the building permitted the photographing of the dust explosions.

The igniting source for the dust cloud was a propane-air flame which was injected into the explosion ducting through two inlet bosses (at D Fig. 1) 1.37 m (4.5 ft) from the cyclone inlet. About 350 cm^3 of propane gas, measured at N.T.P., were used for each experiment. There were two igniting units each as shown in Fig. 3.

Dust concentration

The concentration of the dust cloud in the plant was measured by the method of isokinetic sampling[4] at position Y Fig. 1. The apparatus is shown diagrammatically in Fig. 4. It consisted of a probe 1.9 cm (0.75 in) diameter with its open end in the explosion duct, the other end being connected to the inlet of a small, high efficiency cyclone of top diameter 3.8 cm (1.5 in) and height 13.3 cm (5.25 in) the air outlet of which connected with a high speed fan by way of a solenoid valve. On the outlet side of the fan the air passed through a control valve and flowmeter to atmosphere. The dust, separated in the small cyclone, was collected in a bottle attached to the bottom outlet of the cyclone. The system was operated by remote control. The dust concentration was calculated from the weight of dust collected and the volume of air metered.

Air velocity

The air velocity in the plant was obtained by making measurements with a pitot tube and manometer[5]. Measurements were taken at position Y Fig. 1, which was 2.44 m (8 ft) from the fan outlet and was the furthest distance possible along straight ducting from the fan. An orifice plate was situated in the return air duct (X, Fig. 1)[6] and the pressure differential between points H and L (Fig. 1) was used as an operating indicator of steady conditions within the plant during experiments.

Photography

Cine films of most of the explosions were taken on 16 mm colour reversal film at 24 frames per second.

Pressure measurements

The explosion pressure in the cyclone was measured with a capacity pressure cell at position E, Fig. 1. The output from the cell was amplified and fed into a cathode ray oscilloscope.

Flame detection

The flame detectors used were phototransistors housed in window nuts which were threaded to fit the inlet bosses on the plant. Their outputs were fed into the oscilloscope. The detectors were sited at either two or three positions for each experiment and in the series of experiments positions A, C, D, G, P, M, N and Y (Fig. 1) were used for flame detection. The glass windows in the nuts were kept free from adhering particles of dust by jets of high velocity air passing across them.

Bursting vent covers

150 gauge polyethylene film was used as bursting vent covers. Its bursting pressure was measured in a separate apparatus which consisted of a metal vessel 91.5 cm x 61 cm x 15 cm deep (3 ft x 2 ft x 6 in) with a vent in the lid, the same in shape and size as those on the cyclone. The vent covers were burst with air admitted from a pressurised reservoir by operating a snap action valve 6.3 cm (2.5 in) diameter. The pressure was measured using a capacity pressure gauge as before.

Procedure

The general procedure for determining the explosibility of dust in the cyclone was, firstly to cover the vents of the required area with polyethylene film, then the fan was started and when normal working conditions had been attained, as indicated by the pressure differential across the orifice plate, the air velocity in the ducting was measured with the pitot tube. After starting the rotary valves the dust concentration was measured and this was followed by the injection of the igniting source. If the dust cloud ignited, the resulting explosion was observed and filmed until flame no longer propagated through the open vents. Pressure and flame detection records were also obtained. If the dust cloud did not ignite, dust circulation was continued and the ignition attempt repeated. If necessary a total of three ignition attempts were made with any one dust cloud.

Results

Mean air velocity in the plant.

Determinations in fifty experiments under the same operating conditions, with no dust in suspension gave a mean air velocity in the explosion duct of 473 ± 14 m/min (1550 ± 45 ft/min). All measurements were carried out with the air intake regulator (7 Fig. 1) fully open.

Explosibility in standard tests and cyclone

Table 3 shows the comparison between the explosibility of the dusts in the standard test apparatus[2] and that of the dusts in the cyclone plant.

Table 3

Results of the small-scale standard tests
and explosibility in the cyclone

Dust	Explosibility Class	Test apparatus in which ignition occurred	Minimum ignition temperature (Apparatus) (e) °C	Explosible in cyclone
Cork	I	a - e	400	Yes
Manioc	I (Marginal)	c - e	430	No
Phenol formaldehyde resin	I	a - e	450	Yes
Urea formaldehyde resin	I	a - e	420	Yes
Calcium Citrate	II	e	470	No

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

Dusts were considered to be marginally Class I if they exploded in only some of the apparatus with small sources of ignition.

The explosions in the plant

All the explosions followed a similar pattern to the extent that after ignition of the dust the vent covers burst and flame propagated through the open vents as the fan continued to blow the dust cloud into the cyclone. In some experiments, after the initial flame had died away, and in which the vent in the mixing chamber was open (Fig. 1 Vent 8), there was a second ignition of the dust inside the plant and flame again propagated through the open vents. This did not occur when the vent on the mixing chamber was closed. All explosions propagated away from the igniting source into the cyclone and there was no evidence that flame propagated in the direction opposed to that of the moving dust cloud. In most of the experiments in which explosions occurred flame was observed in the dust hopper and in the return air duct.

The order in which the phototransistors responded when positioned one at each end of the duct showed that the flame travelled down the duct. In some experiments the detectors showed that flame propagated on through the fan, up the delivery duct and back to the cyclone.

Explosion pressure

Fig. 5 is a plot of the maximum explosion pressures obtained against the vent areas used in cork dust explosions. A cork dust explosion in the cyclone plant is shown in Plate 1. The results with dusts other than cork are given in Table 4.

In all the experiments there was a maximum initial positive pressure of about 5 in. (13 cm) W.G. within the plant, this being the pressure at which the fan circulated the air. The pressure values plotted in Fig. 5 and shown in Table 4 allow for the initial pressure.

Table 4

Results obtained with dusts other than cork

Dust	Explosibility Class	Concentration range used in the experiments g/l (oz/ft^3)	Explosion in cyclone	Vent area		Maximum explosion pressure	
				ft^2	m^2	p.s.i.g.	Kg/cm^2
Phenol formaldehyde resin	I	0.28 - 0.32	Yes	4.5	0.42	1.1	0.08
Urea formaldehyde resin	I	0.18 - 0.24	Yes	5.2	0.48	0.3	0.02
Manioc	I (Marginal)	0.15 - 0.51	No	2.6	0.24	-	-
Calcium citrate	II	0.14 - 0.23	No	2.6	0.24	-	-

Position of igniting source

In order to ascertain whether or not explosions could be initiated in the plant at positions other than D (Fig. 1) two other positions were used. They were position A (Fig. 1), which was the nearest one to the outlet from the fan, and in the cyclone itself through a position diametrically opposite position D (Fig. 1). The propane/air mixture used was the same in all experiments and the dust clouds were of cork dust. With two units at position A three of five attempts to ignite were successful and with one igniting unit in the cyclone two of five attempts were successful. With two units at position D all twenty nine attempts resulted in ignition of the dust clouds.

Dust feed

As stated above there was no provision for varying the dust feed from the hopper within narrow limits but with cork dust some experiments were carried out with a metal plate covering about 60 per cent of the outlet area of the dust hopper. With this arrangement and 4.6 Kg (10 lb) of dust in the hopper at the beginning of each experiment the dust concentration was reduced to 0.19 ± 0.01 g/l (0.19 ± 0.01 oz/ft^3). Other cork dust experiments were carried out with the metal plate removed but with the same original dust charge in the hopper. The dust concentration, under those conditions, was 0.25 ± 0.01 g/l (0.25 ± 0.01 oz/ft^3).

Bursting vent covers

The results obtained from the experiments to determine the bursting pressure of polyethylene film are shown in Fig. 6.

DISCUSSION

Cork dust and phenol formaldehyde resin exploded readily in the cyclone plant but the explosions with urea formaldehyde resin were relatively weak. No explosions were obtained with manioc (marginal Class I) and calcium citrate (Class II). In the experiments with manioc the values of the dust concentrations used were all within the explosible range as determined previously in the large scale vertical tube apparatus[7].

These findings indicate that with less explosible dusts the effect of mechanically - produced turbulence in the dust cloud is to reduce and perhaps eliminate the explosible concentration range for static air conditions. The most hazardous occasions with these dusts in industrial plant is therefore likely to be during the starting-up and closing-down operations on the plant.

In the experiments in which flame was observed in the dust hopper it was not clear whether the flame propagated through a dust cloud past a rotary valve or whether the return rotary valve delivered burning dust into the hopper from the cyclone. Further work is necessary to clarify this point.

Since it was not possible to vary the dust concentration greatly the concentrations used in the experiments may not have been those which would give rise to the most severe explosion conditions in the cyclone.

It has been shown (Fig. 6) that the polyethylene film used for vent coverings had a range of bursting pressures, the values depending upon the rate of pressure rise. The values of the bursting pressures obtained were similar to those of the maximum pressure obtained in the cyclone experiments and there was insufficient difference to enable the effect of the area of the vents to be satisfactorily assessed.

Further work is planned for studying the efficiency of open vents using vent covers designed to open at predetermined pressures.

CONCLUSIONS

1. Class I dusts propagated explosions in the cyclone plant and in some experiments flame propagated through all sections of the plant.
2. A marginal Class I dust (Manioc) did not propagate explosions in the cyclone plant.
3. A Class II dust (Calcium citrate) did not propagate explosions in the cyclone plant.
4. It was possible to initiate explosions with the igniting source in various positions in the plant.

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The small scale classification tests were carried out by Miss M. M. Raftery and Mrs. M. D. Harris.

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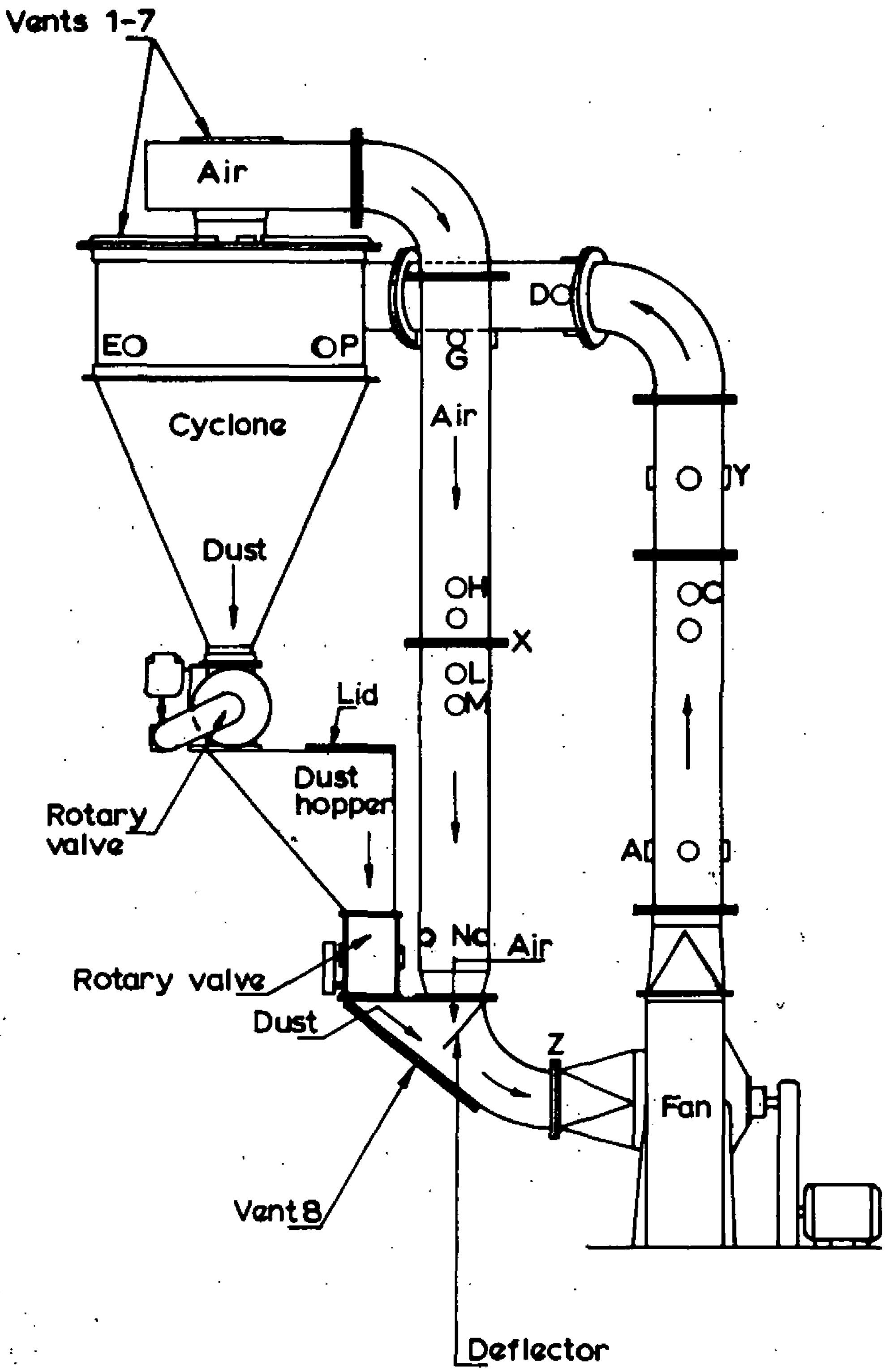


FIG.1. THE CYCLONE PLANT

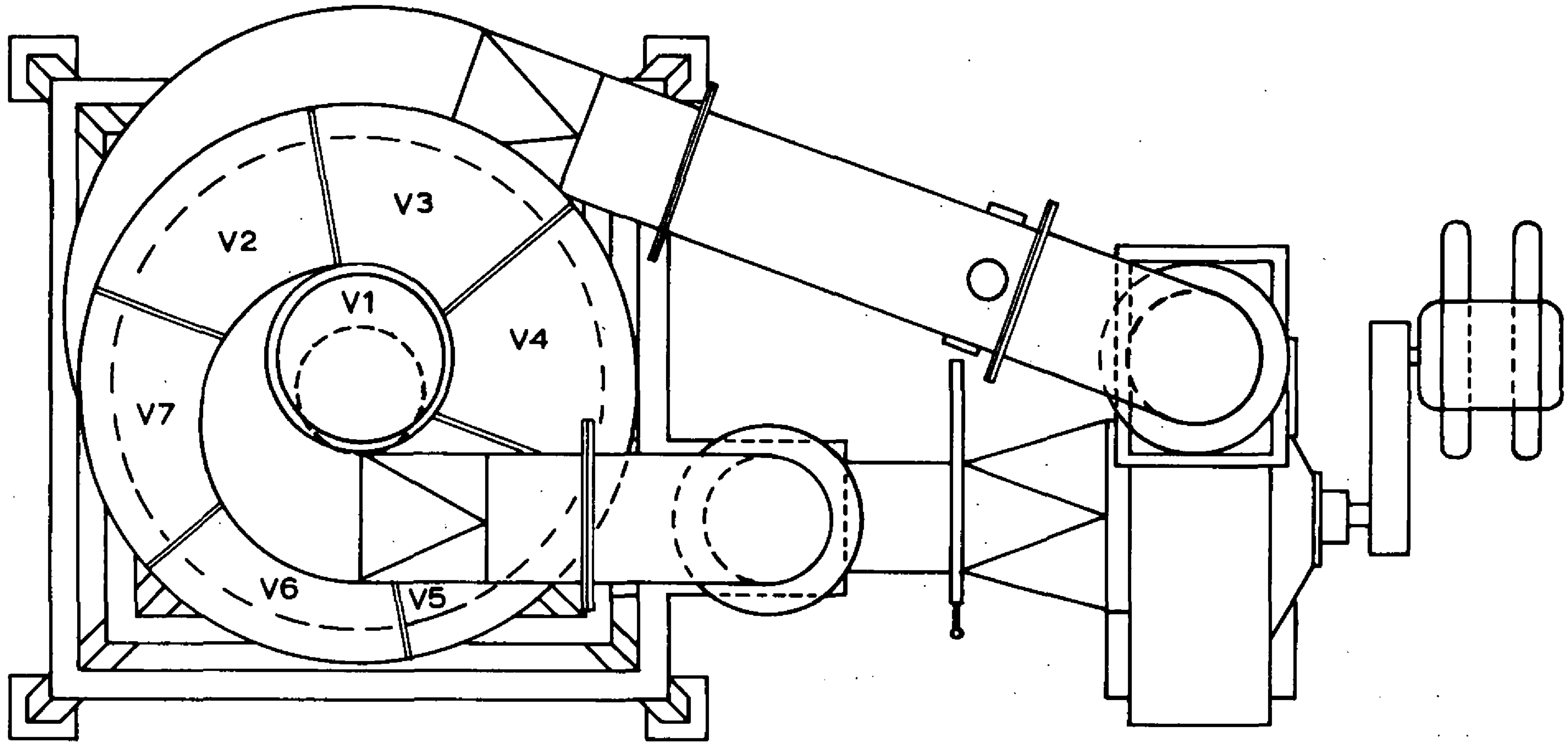


FIG.2. VENTS AT THE TOP OF THE CYCLONE

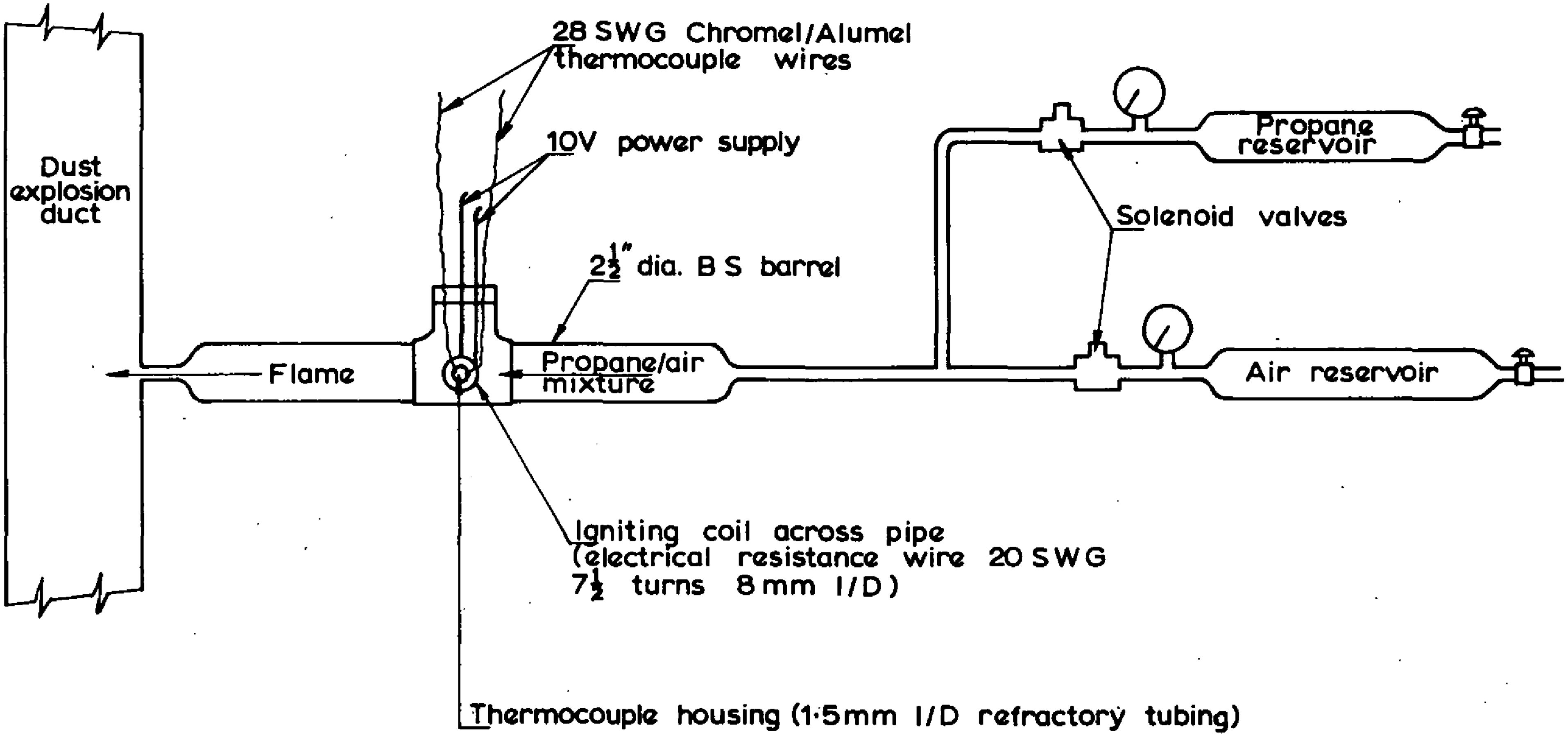


FIG. 3. DIAGRAM OF AN IGNITING UNIT

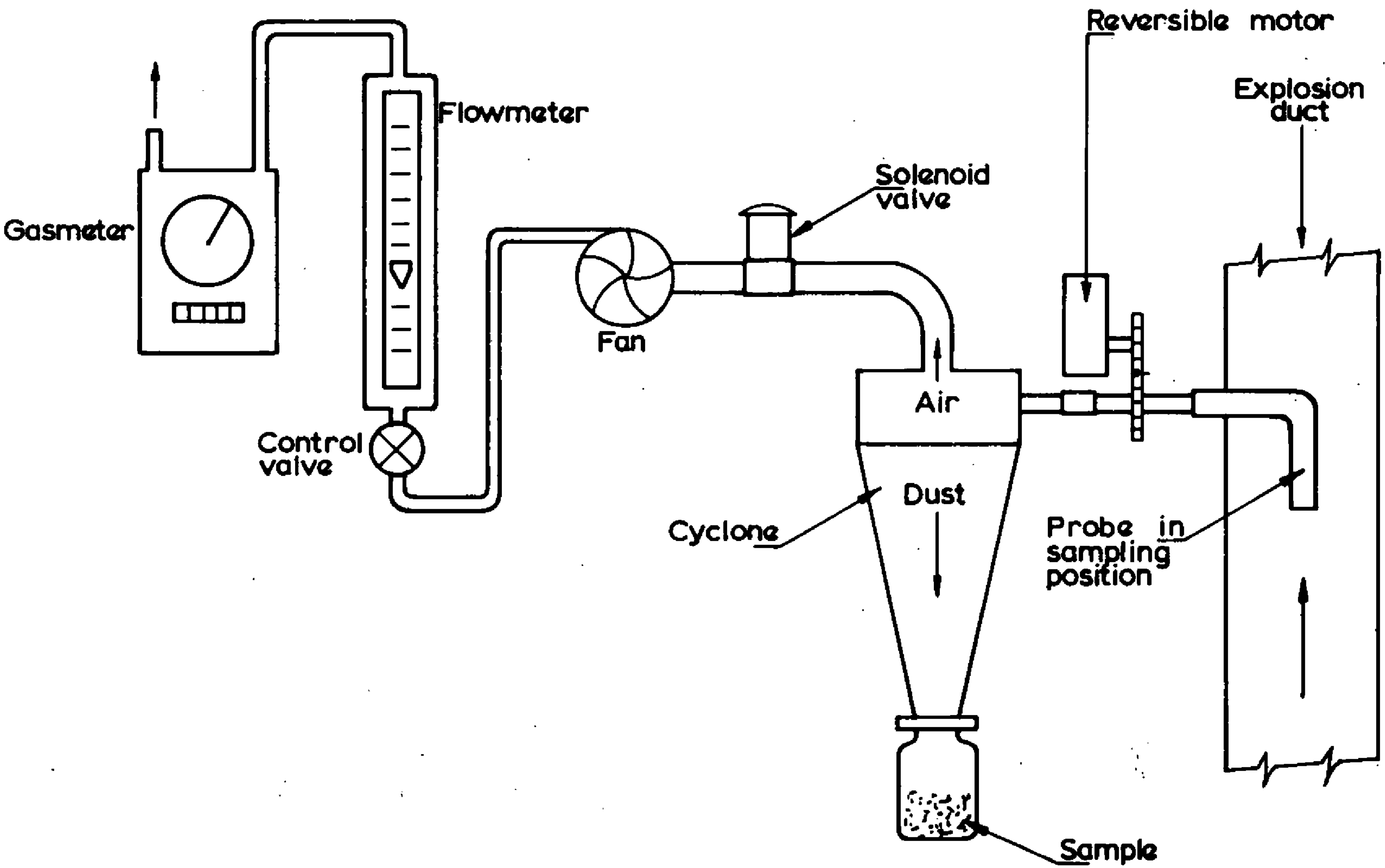


FIG. 4. DUST SAMPLING SYSTEM

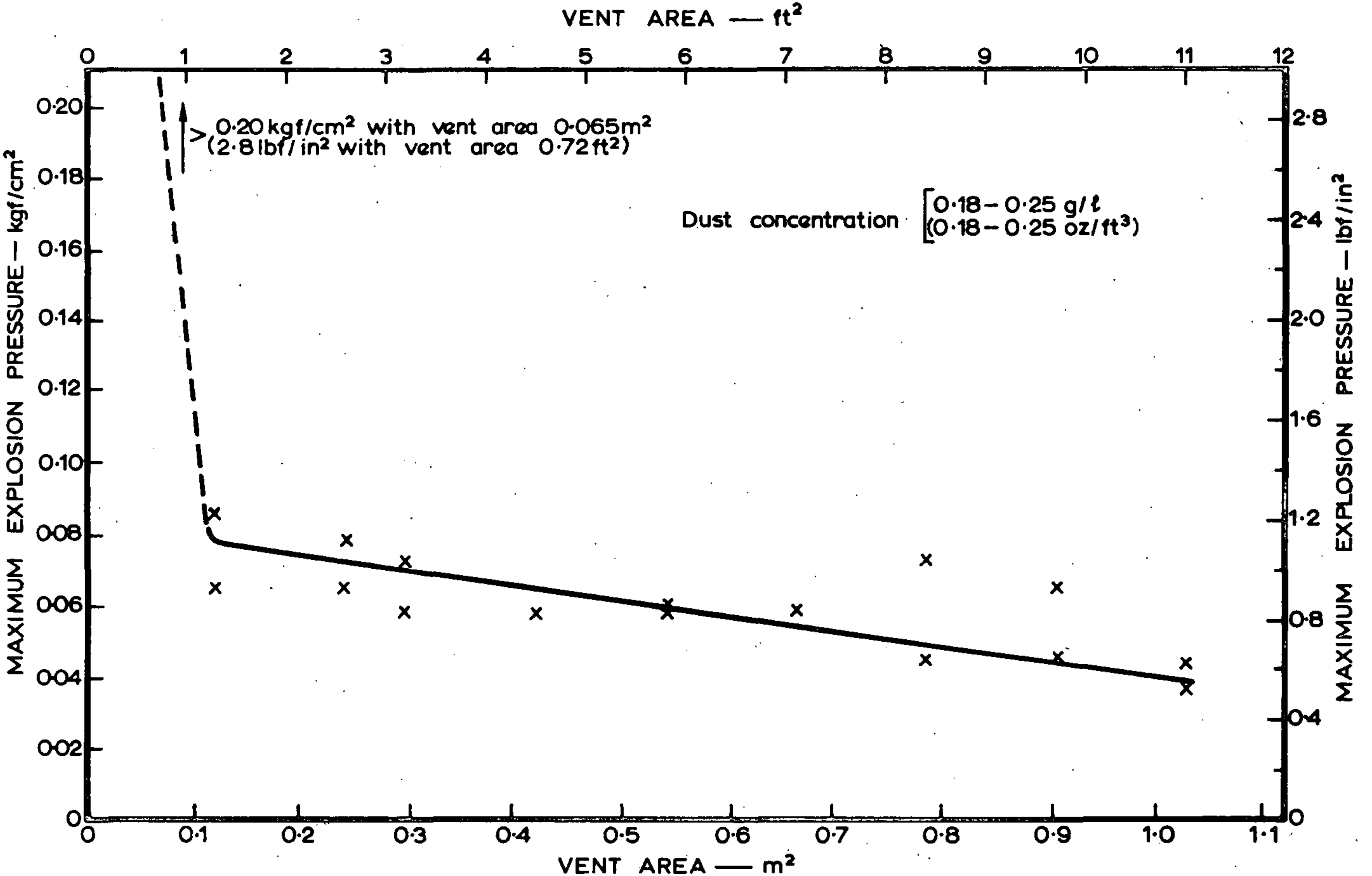


FIG. 5. EXPLOSION PRESSURES — CORK DUST EXPLOSIONS

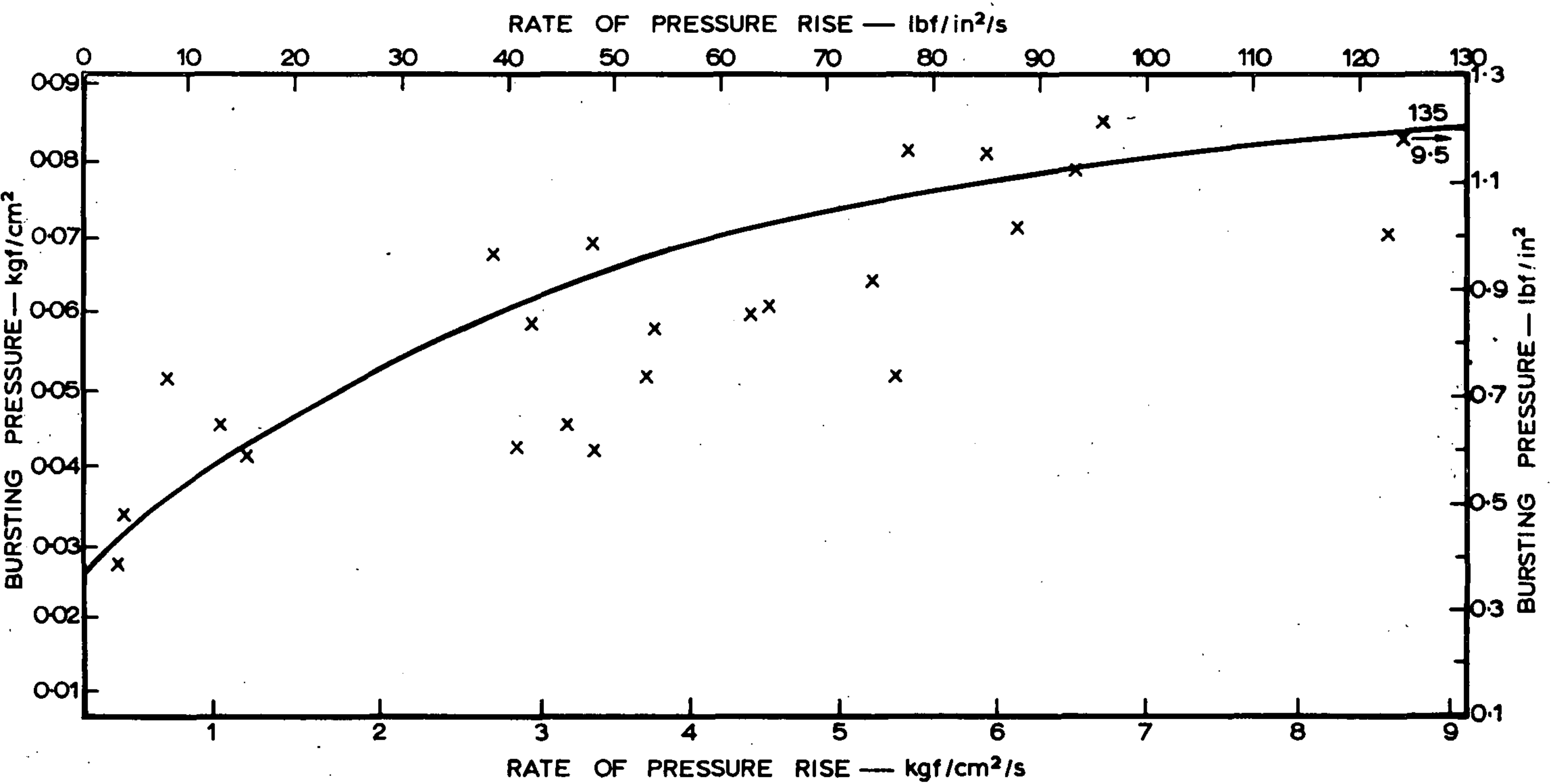
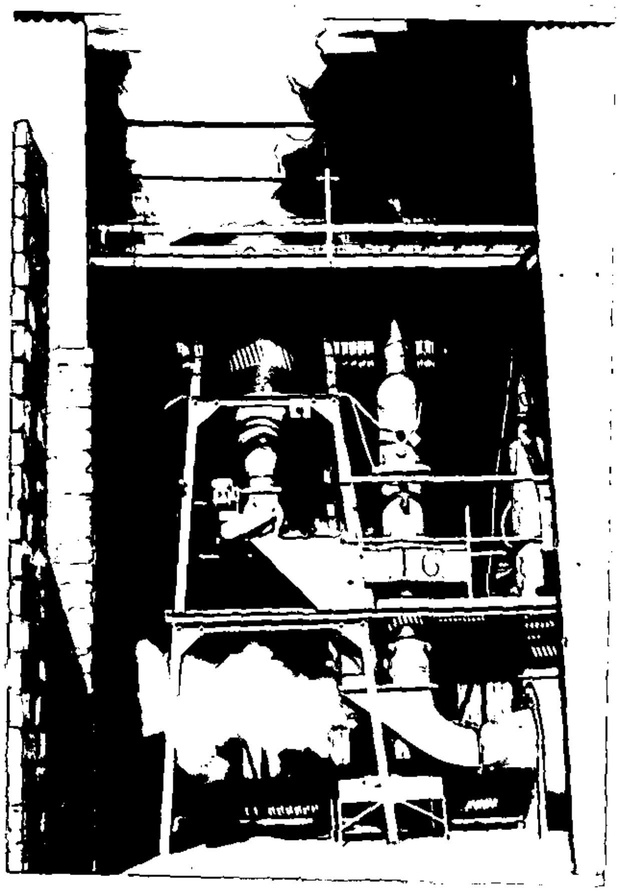


FIG. 6. BURSTING PRESSURE POLYETHYLENE VENT COVERS



dust concentration 0.18 g/l (0.18 oz/ft^3)

total vent area - 0.42 m^2(4.5 ft^2)

PLATE 1 A CORK DUST EXPLOSION IN THE CYCLONE PLANT