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THE PROTECTION OF EQUIPMENT WITH FLAME ARRESTERS PART III PERFORMANCE OF ARRESTERS WITH ETHYLENE-AIR FLAMMABLE MIXTURE.

by

K. N. PALMER AND Z. W. ROGOWSKI

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FIRE
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STATION

Fire Research Station,
Borehamwood,
Herts.
Tel. 01-953-6177

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SUMMARY

Experiments were carried out evaluating the performance of flame arresters when fitted to cubical enclosures. Data are presented giving simple correlation between the area of flame arrester or vent and the maximum explosion pressure in small cubical vessels using 6.5 per cent ethylene-air explosive mixture. The effect of simple obstacles on the maximum explosion pressure was also investigated. These results are compared with the results obtained in the past, using propane-air mixtures.

KEY WORDS: Venting, arresters, obstacles.

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

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INTRODUCTION

The work carried out on the development of a new method of making electrical apparatus safe by the use of flame arresters while functioning in flammable gas environments[1,2] has used propane-air mixtures. In modern chemical and petroleum industry, however, it is common for unsaturated hydrocarbons to accompany paraffins, and for that reason it is customary to provide flameproof equipment which is designed for gases belonging to Groups II and III, B.S.229. Since similar performance would be desirable from equipment protected by flame arresters, some additional work was carried out on the performance of such apparatus in ethylene-air mixtures which represent some of the Group III gases. This note presents results of this work, its object being to provide complementary design data to those obtained with propane-air flammable mixtures.

APPARATUS AND MATERIALS

EXPLOSION VESSELS

Three sizes of cubical vessel were used, with capacities of 9 l (⅓ ft³), 28 l (1 ft³) and 85 l (3 ft³). Each vessel had two open flanged ends giving provision for bolting on covers, which were usually provided with four or five circular vent openings to which flame arresters could be fitted; unused vents were closed by bolting on blank plates. One cover for the 9 l (⅓ ft³) vessel had only one central circular opening 11 cm (4.3 in) in diameter.

Table 1 shows the sizes and the number of vents used with each vessel.

TABLE 1

Number and diameters of vents

Diameter of vents		Volume of explosion vessel		
cm	in	9.1 (⅓ ft³)	28 l (1 ft³)	86 l (3 ft³)
2.9	1.15	5	-	-
5.7	2.25	1	4	-
11.0	4.30	1	1, 2	2, 4

When all vents were situated on one cover it is useful to follow previous practice[1] and to define the area of the vents by the ratio

$$K = \frac{\text{Cross-sectional area of the explosion vessel}}{\text{Area of vent or vents}}$$

All vessels had provision for the insertion of pressure gauges and the igniting source. In all tests other than those with obstacles, the pressure gauge was situated in the centre of one vertical wall of the vessel. In tests with obstacles the gauge was situated near the top cover. The igniting source was either situated in the centre of the vessel or on the vertical axis of the vessel 5 cm (2 in) away from either cover.

The explosion vessel rested inside a 440 l (15.6 ft^3) cubical enclosure, the open side of which was sealed with two layers of 0.0038 cm (0.0015 in) thick polyethylene film.

FLAME ARRESTERS

The arresters were made from nickel ribbon 25 mm (1 in) wide 0.18 or 0.12 mm (0.007 or 0.005 in) thick and consisted of packs of alternate crimped and flat ribbons mounted in square metal cases. Circular holes in the cases, of diameters 11 cm (4.3 in) and 2.9 cm (1.15 in) allowed discharge of gas through the arresters. All had a crimp height of 0.5 mm (0.020 in).

OBSTACLES

The orifice plates and the shelves were made from 0.3 cm ($\frac{1}{8}$ in) thick mild steel sheet. The sides of the obstacles were secured to the wall of the explosion vessel by two or three set screws. Figure 1 shows orifice and shelf obstacles each obstructing 25 per cent of the cross-sectional area of the explosion vessel. In all tests the obstacles were mounted parallel to the arresters and were situated either 2.0 cm (0.8 in) above the centre of the vessel (central), or 3.8 cm ($1\frac{1}{2}$ in) away from top cover (near), or 6.3 cm ($2\frac{1}{2}$ in) away from the bottom cover (remote). With each position of the obstacles the igniting source was either in the centre of the vessel or on its vertical axis 5.1 cm (2 in) away from the top or bottom cover.

The perforated obstacles consisted of brass sheet perforated with 0.56 cm (0.22 in) holes and mounted in a light aluminium frame.

Tables 2 and 3 give details of the obstacles used for the 28 l (1 ft^3) and 9.1 ($\frac{1}{3}$ ft^3) explosion vessels respectively.

TABLE 2

Details of the obstacles used in 28 l (1 ft^3) explosion vessel

Type of obstacle	Per cent of cross-sectional area of the explosion vessel blocked
Shelf	25
	50
Perforated metal	56

TABLE 3

Details of the obstacles used in 9 l ($\frac{1}{3}$ ft^3) explosion vessel

Type of obstacle	Per cent of cross-sectional area of the explosion vessel blocked
Shelf	25
	50
	75
Orifice plate	25
	50
	75

FLAMMABLE GAS

A 6.5 per cent by volume ethylene-air mixture was used throughout the tests; the explosion vessels were filled by the displacement of air.

IGNITION

In all experiments the flammable gas was ignited by an inductive spark. This was delivered from a 12 volt car induction coil across a 1 mm gap between electrodes. The spark gap was always situated on the vertical axis of the vessel in the centre or 50 mm (2 in) away from the top or bottom flange, thus in the last two positions it was near or remote from the vent correspondingly. When the obstacle and the igniting source were both nominally at the centre of the vessel the igniting spark was produced on the side of the obstacle remote from the arresters.

PROCEDURE

The ethylene-air mixture was fed into the explosion vessel and passed into the outer enclosure through the flame arresters and from there ran to waste. A volume of gas equal to ten changes of the larger enclosure was used for each experiment; throughout the charging period the gas in the outer enclosure was stirred by a fan. After charging was completed the flammable mixture in the explosion vessel was ignited. Absence of explosion in the outer enclosure indicated that the arresters contained the explosion within the explosion vessel.

Visual examination of the arresters was made with every rig after the completion of the tests. With arresters which were expected to suffer damage, inspection was carried out after each test.

RESULTS

EXPLOSION IN UNOBSTRUCTED VESSELS

With explosions in unobstructed vessels the pressure/time curves were smooth during the period while the flame front moved to the vent. After this various vibrations developed, many of acoustic nature. Possible effects of the vessel wall on the gauge performance were investigated, by the use of various elastic mountings for the gauge seat, and it was established that none of the readings were spurious.

Usually explosions with the ignition near the vent gave pressure records of longer duration and these often showed absence of pronounced peaks. The maximum explosion pressure could occur long after the flame front reached the arrester and this ignition position gave the lowest maximum pressures. With multiple vents ignition remote from the vent always resulted in highest maximum pressures. With a single vent, however, there was little difference between the maximum pressure with ignition remote or at the centre. The peak pressures, however, with both single and multiple vents occurred either when the flame reached the vent or soon after. The shapes of the pressure/time curves obtained with and without arresters were very similar. Figure 2 shows maximum explosion pressures for various explosion vessels with open vents. The line previously obtained with propane-air[1] is shown for comparison; Fig.3 shows the maximum explosion pressures for the same vents covered by flame arresters, these pressures are about twice as high as with open vents. Experiments carried out in the 85 l (3 ft^3) vessel, indicate that for a given K value the maximum pressure in this vessel was twice the value of the pressures obtained in smaller explosion vessels, both for vents covered with flame arresters (Fig.3) and for open vents.

Tables 4 and 5 show the ranges of flame speeds obtained with various vessels and vents. The magnitude of speed varied according to the relative position of vent and ignition, as follows. Slowest speeds were noted when the ignition source was near the vent, and ignition remote from the arrester resulted in highest speeds. If, however, a single arrester or vent was used, speeds were little different from those obtained with ignition remote from the arresters. The propagation of the flame front towards the arrester was always fastest, with the exception of some tests with the ignition near the vent.

TABLE 4

Ranges of flame speeds in 9 l ($\frac{1}{4}$ ft^3) explosion vessel

Open vents

K	13	17	5
No. of vents	5	1	1
Diameter of vents cm in	 2.9 1.15	 5.7 2.25	 11.0 4.3
Ranges of speed m/s ft/s	 2.4-8.8 8-29	 2.4-11.6 8-38	 2.4-11.4 8-32

Vents fitted with arresters

K	13	17	5
No. of arresters	5	1	1
Diameter of arresters cm in	 2.9 1.15	 5.7 2.25	 11.0 4.3
Ranges of speeds m/s ft/s	 3.0-9.2 10-30	 2.7-11.0 9-36	 2.4-12.2 8-40

TABLE 5

Ranges of flame speeds

28 l (1 ft^3) explosion vessel vents
fitted with arresters

K	9
No. of arresters	4
Diameter of arresters cm in	 5.7 2.25
Ranges of speeds m/s ft/s	 2.7-9.2 9-30

85 l (3 ft^3) explosion vessel vents
fitted with arresters

K	10	5
No. of arresters	2	4
Diameter of arresters cm in	 11.0 4.3	 11.0 4.3
Ranges of speeds m/s ft/s	 2.4-18.2 8-60	 1.8-17.0 6-56

TESTS WITH OBSTACLES

Tables 6 and 7 show the maximum explosion pressures in the 28 l (1 ft^3) explosion vessel with different vent arrangements using shelf obstacles. Tables 8 and 9 show the maximum explosion pressures in the 9 l ($\frac{1}{3}$ ft^3) explosion vessel using shelf and orifice place obstacles. The results shown in these Tables have certain common characteristics. The maximum explosion pressures depended very much on the area of all obstacles. The positioning of the obstacle did not have a great effect on the maximum pressure but the position of the igniting source affected the maximum pressure greatly. As a rule the igniting source remote from the arrester resulted in the highest maximum pressures.

When the highest pressure obtained with any type of obstacle is compared with the maximum explosion pressure in the corresponding empty vessel, the obstacle caused increases varying between factors of 2.5 to 3.0 for both explosion vessels.

Table 10 shows the maximum explosion pressures obtained with the perforated metal obstacle. These results are directly comparable to shelf obstacle blocking 50 per cent area of the same explosion vessel. The highest pressure recorded with the perforated metal obstacle is 2.8 times the pressure recorded with the empty vessel.

THERMAL DAMAGE TO ARRESTER RIBBON

Throughout the test period, record was kept of the thermal damage sustained by the arrester. This appeared to be of the same order as damage reported while using propane-air mixtures[1], and in no case structural damage to the arrester ribbon was noted.

TABLE 6

Effect of shelf obstacles on maximum explosion pressure
28 l (1 ft^3) explosion vessel
2 arresters 11.0 cm (4.3 in) in diameter (K = 5)
Maximum explosion pressures kgf/cm^2 (lbf/in^2)

Ignition position	No obstacle	Position of obstacle blocking 25 per cent of the area			Position of obstacle blocking 50 per cent of the area		
		Remote	Central	Near	Remote	Central	Near
Remote	0.15 (2.1)	0.22 (3.1)	0.24 (3.5)	0.24 (3.4)	0.31 (4.4)	0.36 (5.1)	0.31 (4.4)
Central	0.09 (1.3)	0.12 (1.8)	0.11 (1.6)	0.10 (1.4)	0.13 (1.8)	0.14 (2.0)	0.14 (2.0)
Near	0.07 (1.0)	0.07 (1.0)	0.08 (1.2)	0.06 (0.9)	0.08 (1.1)	0.07 (1.0)	0.06 (0.8)

TABLE 7

Effect of shelf obstacles on maximum explosion pressure
28 l (1 ft^3) explosion vessel
1 arrester 11.0 cm (4.3 in) in diameter (K = 10)
Maximum explosion pressures kgf/cm^2 (lbf/in^2)

Ignition position	No obstacle	Position of obstacle blocking 25 per cent of the area			Position of obstacle blocking 50 per cent of the area		
		Remote	Central	Near	Remote	Central	Near
Remote	0.42 (6.0)	0.46 (6.5)	0.62 (8.8)	0.65 (9.3)	N.D.	1.0 (14.6)	1.27 (18)
Central	0.41 (5.8)	0.56 (7.9)	0.51 (7.3)	0.48 (6.8)	N.D.	0.63 (9.0)	0.76 (10.7)
Near	0.25 (3.1)	0.34 (4.8)	N.D.	0.21 (3.0)	N.D.	0.42 (6.0)	0.28 (4.0)

N.D. Not determined.

TABLE 8

Effect of shelf obstacles on maximum explosion pressure

9 l ($\frac{1}{3}$ ft^3) explosion vessel

5 arresters 2.9 cm (1.15 in) in diameter (K = 13)

Maximum explosion pressure kgf/cm^2 (lbf/in^2)

		Position of obstacle blocking 25 per cent of the area			Position of obstacle blocking 50 per cent of the area			Position of obstacle blocking 75 per cent of the area		
Ignition position	No obstacle	Remote	Central	Near	Remote	Central	Near	Remote	Central	Near
Remote	0.70 (10.0)	0.74 (10.5)	0.86 (12.3)	0.82 (11.8)	1.05 (15.0)	1.27 (18.0)	1.14 (16.3)	1.27 (18.2)	1.62 (23.0)	1.76 (25.0)
Central	0.56 (8.0)	0.64 (9.1)	0.45 (6.4)	0.47 (6.7)	0.69 (9.8)	0.67 (9.5)	0.65 (9.3)	0.45 (6.5)	0.82 (11.8)	0.93 (13.3)
Near	0.22 (2.8)	0.30 (4.25)	0.36 (5.1)	0.24 (3.1)	0.20 (2.8)	0.39 (5.6)	0.21 (3.0)	0.20 (2.8)	0.25 (3.5)	0.36 (5.2)

TABLE 9

Effect of orifice obstacles on maximum explosion pressures

9 l ($\frac{1}{3}$ ft^3) explosion vessel

5 arresters 2.9 cm (1.15 in) in diameter (K = 13)

Maximum explosion pressures kgf/cm^2 (lbf/in^2)

		Position of obstacle blocking 25 per cent of the area			Position of obstacle blocking 50 per cent of the area			Position of obstacle blocking 75 per cent of the area		
Ignition position	No obstacle	Remote	Central	Near	Remote	Central	Near	Remote	Central	Near
Remote	0.70 (10.0)	0.88 (12.5)	0.97 (13.8)	1.13 (16.0)	0.74 (10.5)	1.1 (15.0)	0.70 (16.3)	0.70 (10.0)	0.70 (12.0)	1.55 (22.0)
Central	0.56 (8.0)	0.51 (7.3)	0.61 (8.7)	0.70 (10.0)	0.46 (6.5)	0.48 (6.8)	0.61 (8.7)	0.65 (9.3)	0.50 (7.1)	0.65 (9.3)
Near	0.22 (2.8)	0.21 (3.0)	0.23 (3.3)	0.22 (3.1)	0.22 (3.1)	0.22 (3.1)	0.25 (3.5)	0.42 (6.0)	1.31 (18.6)	0.23 (3.3)

TABLE 10

Effect of perforated metal obstacle on maximum explosion pressures
2 arresters 11.0 cm (4.3 in) in diameter (K = 5)
28 l (1 ft^3) explosion vessel
Maximum explosion pressures kgf/cm^2 (lbf/in^2)

Ignition position	No obstacle	Position of obstacle		
		Remote	Central	Near
Remote	2.1	0.16 (2.3)	0.41 (5.9)	0.25 (3.6)
Central	1.3	0.17 (2.4)	0.14 (2.0)	0.13 (1.8)
Near	1.0	0.11 (1.5)	0.12 (1.8)	0.05 (0.8)

DISCUSSION

VESSELS WITHOUT OBSTACLES

In all vented explosions two different processes may be distinguished. One is the exothermic reaction between the flammable gas and the oxidant; this reaction produces a greatly increased volume of reaction products. The other process is the ejection of the expanded or cold gases through a vent provided for the purpose. The maximum explosion pressure in a vessel results from the action of these two opposing phenomena. The reaction rate governs the rate of expansion of the gases and the size of the vent governs the volume of gases expelled. By equating the rate of generation of combustion products with the rate of venting, the maximum explosion pressure can be calculated[1]. Good agreement was obtained between measured and calculated maximum explosion pressures for propane-air mixtures. This theory predicts that the maximum pressure for a given K will increase with the square of the measured flame speed between the igniting source and the vent. The range of measured relevant flame speeds for ethylene-air flammable mixture is 9.2-12.2 m/sec (30-40 ft/sec) for 9 l ($\frac{1}{3}$ ft^3) and 28 l (1 ft^3) vessels and this compares with 5.5-6.2 m/sec (18-20 ft/sec) obtained with propane-air mixture for the same vessels. The square of the ratio of these two quantities varies between 2.5-4. The ratio of the maximum explosion pressures with ethylene-air and propane-air is close to the maximum value of this range. The maximum explosion pressures recorded in 85 l (3 ft^3) explosion both for propane-air and ethylene-air flammable mixtures were about twice the corresponding pressures obtained with the smaller vessels. The relevant maximum flame speeds measured with ethylene-air flammable mixture are approximately 1.5 times those measured with the other explosion vessels, and they justify the recorded increase in the explosion pressure. No corresponding maximum flame speeds with propane-air mixture while using arresters are available for comparison.

The higher maximum explosion pressures obtained with the larger vessels are not entirely surprising, as other work with larger containers produced higher values, and it was indicated that the high combustion rates were caused by the turbulence within the flame zone[3].

It would be desirable to correlate the maximum explosion pressure with the fundamental burning velocity, as this could enable predictions to be made for a variety of gas mixtures. Such correlation, however, could only be valid if the rates of burning remained constant for a variety of experimental conditions. Present results indicate, however, that the rates of burning may be subject to variation caused by the size of explosion vessels, thus making such extrapolation difficult for larger vessels.

VESSELS WITH OBSTACLES

Extensive tests with obstacles while using propane-air mixtures have already been described[2]. This work showed the effect of various obstacles on the maximum explosion pressure, but although a great deal of experimental work was carried out no simple relationship was found between the shape of obstacle and the maximum explosion pressure.

Direct comparison may now be made between the highest maximum pressures for any given obstacle with propane-air and ethylene-air flammable mixtures. Table 11 shows this comparison for both 28 l (1 ft^3) and 9 l ($\frac{1}{3}$ ft^3) explosion vessels with various obstacles.

TABLE 11

Ratio of the maximum explosion pressures

$\frac{\text{Ethylene - air}}{\text{Propane - air}}$ obtained with various obstacles

	Cross-sectional area blocked by obstacle		
	25 per cent	50 per cent	75 per cent
28 l (1 ft^3) vessel shelf obstacle K = 5	3.9	4.6	N.D.
9 l ($\frac{1}{3}$ ft^3) vessel shelf obstacle K = 13	1.3	2.9	3.0
28 l (1 ft^3) vessel perforated metal K = 10	N.D.	5.0	N.D.

N.D. Not determined

APPLICATION OF THE RESULTS

The results described widen the scope of the existing design data. They indicate the maximum explosion pressures that will be produced by some of the Group III gases. They also indicate that the maximum explosion pressures in small cubical vessels with no obstructions are predictable with some measure of accuracy. The effect of contents is not easily predictable and only some guidance is available from the data obtained with simple obstacles. As most of the containers requiring protection will have great variety of obstacles, the assessment of the maximum explosion pressures in such containers will be subject to tests.

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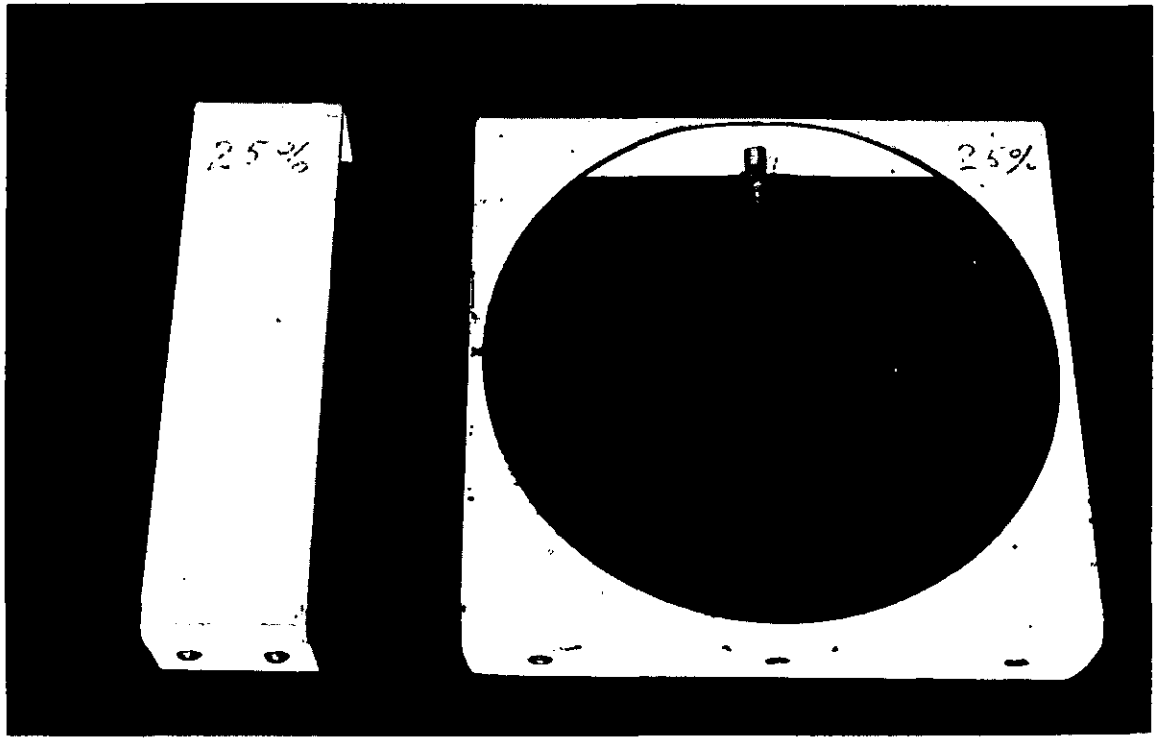
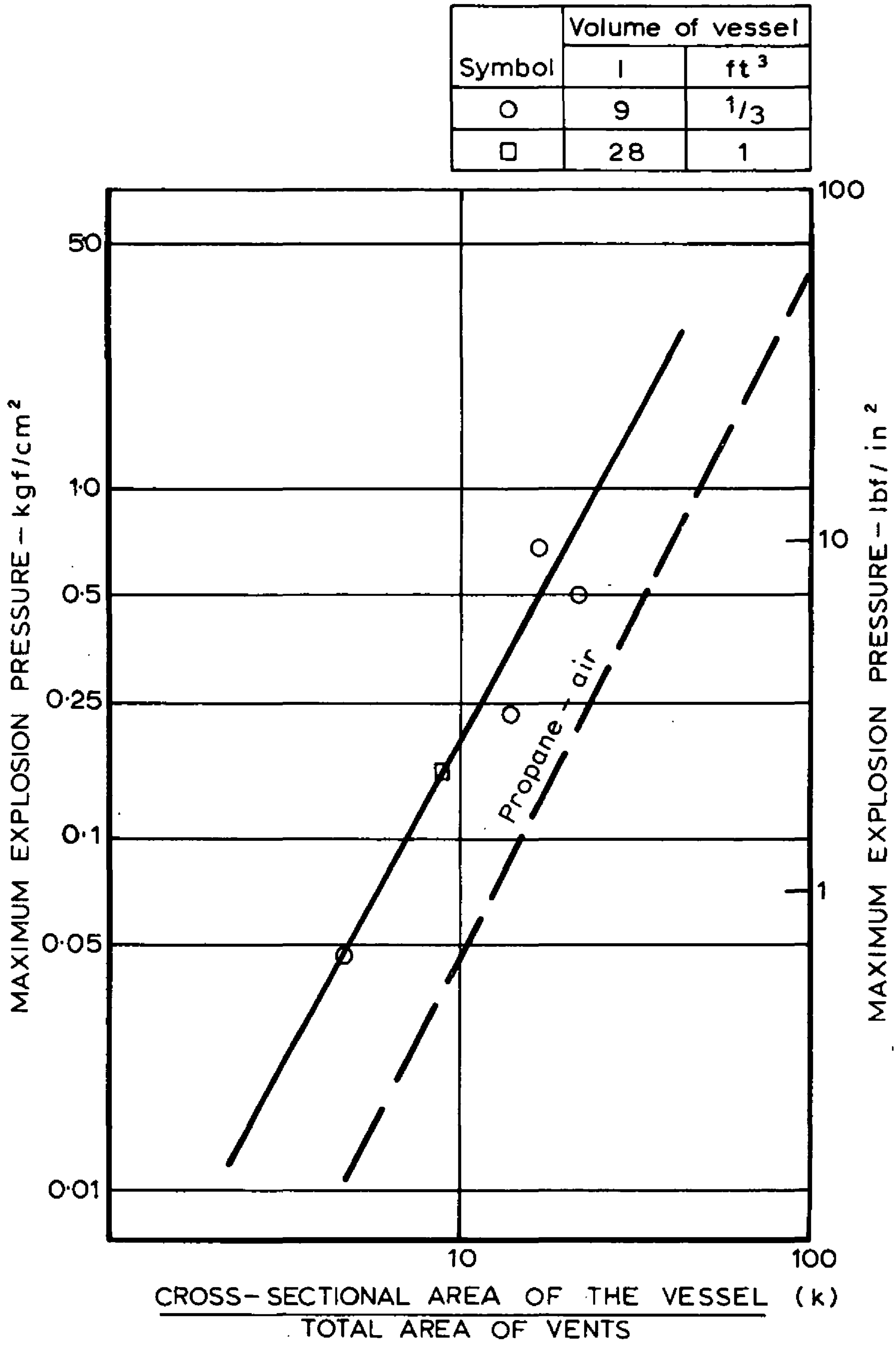


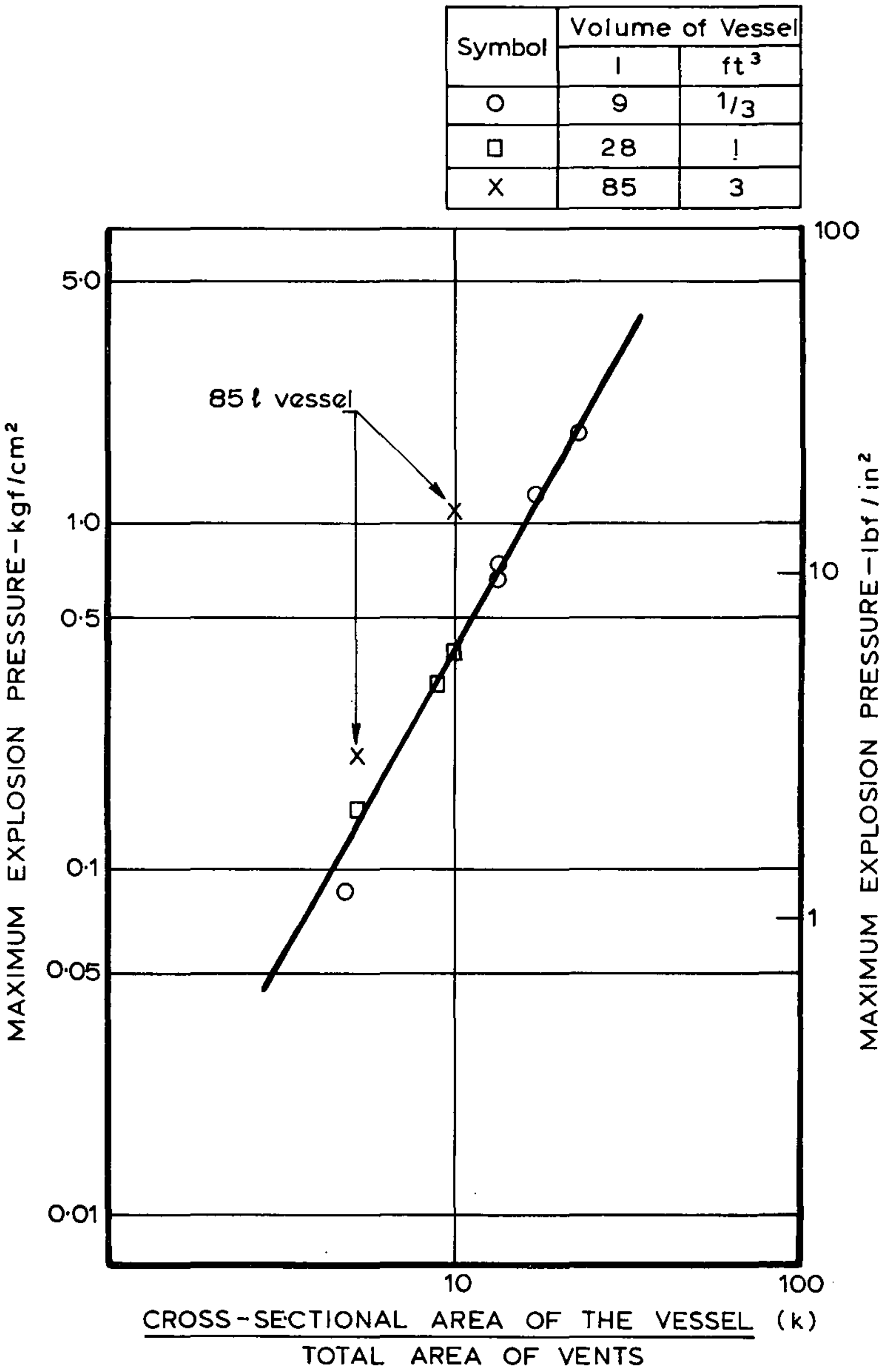
ORIFICE AND SHELF OBSTACLES BLOCKING
25 PER CENT OF THE CROSS-SECTIONAL
AREA OF THE VESSEL

FIG. 1



Symbol	Volume of vessel	
	l	ft³
○	9	1/3
□	28	1

FIG. 2. RELATIONSHIP BETWEEN MAXIMUM EXPLOSION PRESSURE AND THE VENT AREA OPEN VENTS 6·5 PER CENT ETHYLENE-AIR



Symbol	Volume of Vessel	
	l	ft³
○	9	1/3
□	28	1
X	85	3

FIG. 3. RELATIONSHIP BETWEEN MAXIMUM EXPLOSION PRESSURE AND THE VENT AREA VENTS COVERED WITH FLAME ARRESTERS 6·5 PER CENT ETHYLENE – AIR

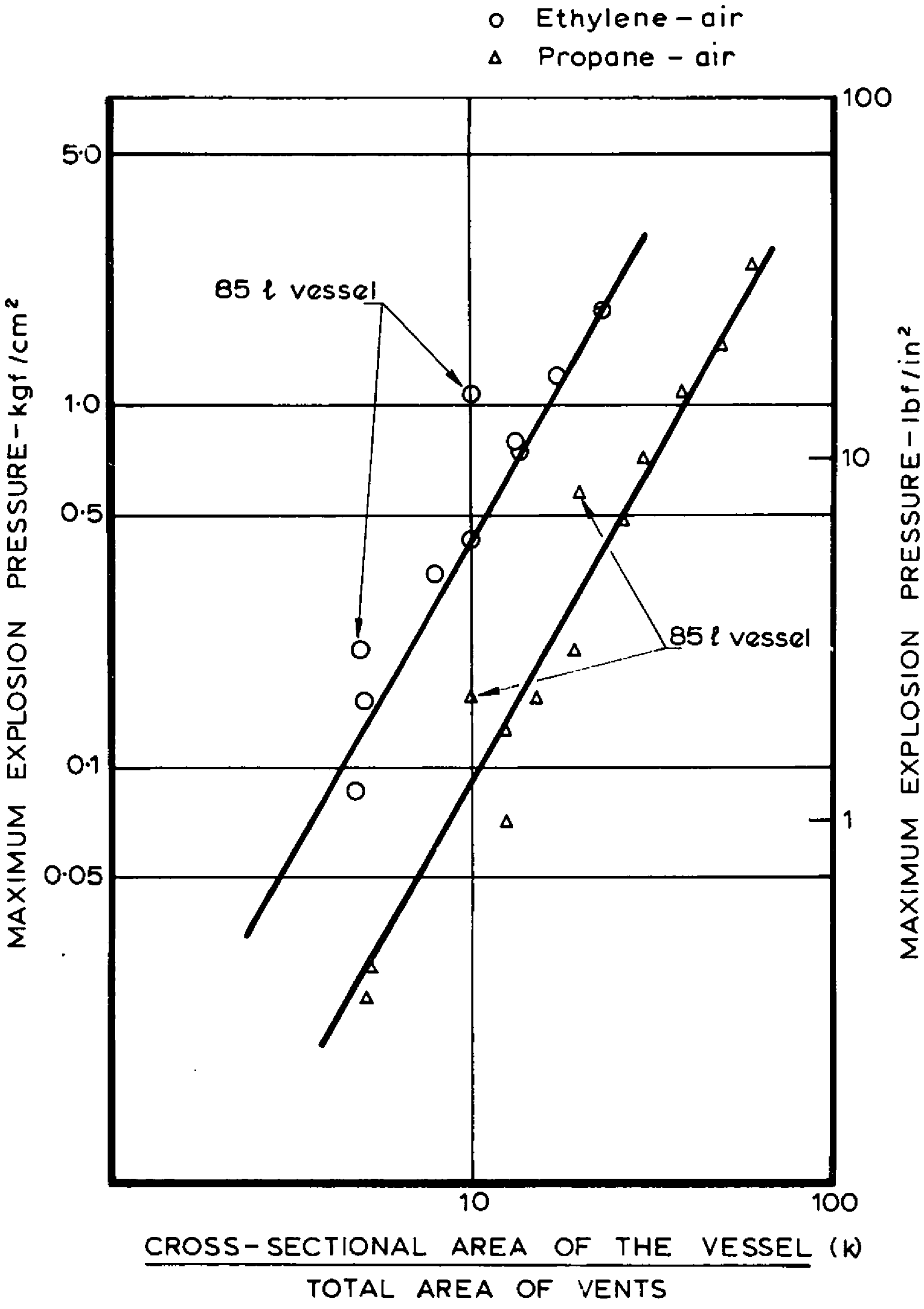


FIG. 4. RELATIONSHIP BETWEEN MAXIMUM EXPLOSION PRESSURE AND THE VENT AREA VENTS FITTED WITH FLAME ARRESTERS PROPANE AND ETHYLENE-AIR