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THE EFFECT OF EXPLOSION PRESSURE RELIEF ON THE MAXIMUM EXPERIMENTAL SAFE GAPS OF PROPANE-AIR AND ETHYLENE-AIR MIXTURES

by

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SUMMARY

The effect of relief vents protected with flame arresters on the maximum experimental safe gaps of 4.2 per cent propane-air and 6.5 per cent ethylene-air flammable mixtures was investigated using an explosion vessel of volume 8 l. Flanges of the following nominal breadths were used: 25 mm (1 in), 12.5 mm (½ in), 6 mm (¼ in), 3.2 mm (⅛ in) and 1.6 mm (1/16 in).

Under the most critical conditions for the gas mixtures the MESG was marginally affected when reliefs were present. The maximum explosion pressure was increased by obstacles within the explosion vessel but the MESG remained unchanged.

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

Work carried out at Fire Research Station on use of flame arresters for the protection of equipment in flammable atmospheres[1,2] has shown that equipment of light construction could be used because explosion pressures were much reduced. This could accommodate flanges or other closures of small breadths, eg between the lid and the equipment casing, and design data for such closures was required. Also it was not clear whether the presence of reliefs covered with arresters would have any effect on the performance of flange gaps with propane-air and ethylene-air flammable mixtures, in explosion vessels either empty or fitted with internal obstacles or contents. This note describes experiments evaluating the performance of flanged gaps of various breadths when working under these conditions.

APPARATUS AND MATERIALS

Explosion vessel

The maximum experimental safe gaps were determined using an 8 litre stainless steel cylinder of height and internal diameter 216 mm (8.5 in), and 25 mm (1.0 in) wall thickness. The top and bottom of the vessel consisted of separate end plates, 25 mm (1.0 in) thick, which could be kept apart from the cylindrical wall by silver foil shims. The cylinder was sandwiched between two end cups (Fig. 1). All contact surfaces between the end cups, end plates and the cylinder were finished to an accuracy of ± 0.006 mm (0.00025 in). The arrester was held in a mild steel mount, which in turn was bolted to the top flange (Fig. 1). The assembly was held together in a press (Fig. 2) in which a hydraulic ram exerted 7½ tons axial compression on the whole cylinder assembly. The yield of the frame holding the cylinder under maximum experimental stress did not exceed 0.006 mm (0.00025 in). Such maximum experimental stresses were achieved only during explosions in a totally closed vessel.

The test cylinder was provided with a gas inlet, via a non-return valve, a pressure transducer and spark electrodes permitting ignition in various positions inside the cylinder (Fig. 1).

The whole cylinder assembly was enclosed in a 0.05 mm thick polyethylene sleeve which contained the flammable mixture during the experiments. This sleeve burst if the ignition of the flammable mixture surrounding the test vessel took place. It remained intact if there was no explosion transmission.

Flange caps

The experimental flange gaps were produced by six stacks of 25 x 13 mm silver shims equally spaced between the cylinder and the upper end plate (see Figs. 1 and 3). The shims were measured using a micrometer before being put in, and the gap finally verified with feeler gauges after the apparatus was compressed by the hydraulic ram.

For flange gaps of radial breadth less than 25 mm (1 in) a number of flange adaptor rings were manufactured, Fig. 4, having effective radial flange breadths of 12.7 mm ($\frac{1}{2}$ in), 6.4 mm ($\frac{1}{4}$ in), 3.2 mm ($\frac{1}{8}$ in) and 1.6 mm ($^{1}/16$ in). These adaptor rings were placed between the top of the cylinder and the upper end plate. The same method of spacing was used to produce the experimental gaps as for the 25.4 mm (1 in) flanges. Three locating shoes were attached to each ring to prevent movement during the explosion, (Fig. 5).

Method of ignition

The flammable mixture was ignited inside the vessel by means of an inductive spark generated between a pair of spark electrodes 2 mm apart, using a 12 volt automotive induction coil.

In the majority of the tests the spark electrodes were placed 10 mm from the inner lip of the gap and midway between two of the stacks of shims as shown in Figs. 3 and 6. In other tests the mixture was either ignited in the centre of the vessel or at a point 10 mm below the flame arrester situated in the centre of the upper end plate (Fig. 1).

Flame arresters

Crimped ribbon flame arresters of 29 mm (1,15 in), 57.5 mm (2.25 in) and 110 mm (4.3 in) diameter were used. All arresters were 38 mm thick and had a crimp height of 0.6 mm (0.024 in). The ribbon thickness was 0.07 mm.

Obstacles

In some of the tests an obstacle was placed inside the test vessel. There were two obstacles in the form of orifice plates, each having a single central hole, and providing 50 per cent and 90 per cent blockages of the cross-sectional area of the test vessel respectively. The orifice plates were fixed one at a time inside the vessel 102 mm (4 in) below the rim, by means of a retaining ring (Fig. 7).

Flammable mixtures

The flammable mixtures used during the investigation were:

4.2 per cent by volume propane in air
6.5 per cent by volume ethylene in air

The mixtures were produced by passing the appropriate gases through flow meters, and subsequently mixing them in a packed column, before being passed into the apparatus via a manual valve and a non-return valve.

Pressure measurement

The pressures developed inside the test vessel were measured by means of a piezo pressure transducer screwed into the lower end plate of the cylinder. The signal from the transducer was passed via a charge amplifier to a cathode ray oscilloscope from which photographs of the time resolved pressure trace could be obtained using a polaroid camera.

PROCEDURE

The procedure used for the determination of a maximum experimental safe gap was as follows: an estimate of the maximum gap was made and six sets of silver shims were selected, with the aid of a micrometer, having a thickness a little over that anticipated for the gap. These were placed equally around the rim of the top of the cylinder as shown in Fig. 3. The end plate of the vessel was placed on the cylinder followed by the end cup. A polyethylene sleeve was placed over the apparatus and a hydraulic ram operated to compress the 'assembly' until a total force of $7\frac{1}{4}$ tons had been achieved. Then the experimental gap was checked using feeler gauges. The polyethylene sleeve was then sealed, top and bottom, and, with the exhaust valve open, the flammable mixture was passed through the whole apparatus until ten complete changes of atmosphere inside the vessel and inside the polyethylene sleeve had been achieved. The gas flow was then shut off and the inlet and exhaust valves closed.

The mixture inside the test vessel was ignited and the pressure developed was recorded from the oscilloscope by a polaroid camera. Bursting of the polyethylene sleeve indicated the transmission of the explosion.

Several tests were carried out before altering the gap. When the maximum experimental safe gap (MESG) was thought to have been achieved, at least twenty tests were carried out, and if no ignition of the outer mixture occurred this was recorded as the MESG for that particular set of conditions.

RESULTS

The effect of flange breadth and gap width on MESG

The results obtained with various flange breadths for unvented and vented explosions are listed in Tables 1 and 2 respectively.

The results with the 25 mm (1 in) flange breadth are plotted in Fig. 8, to show the effect of relief venting. Evidently in all tests the MESG obtained with reliefs were equal or marginally larger than in unvented experiments. The relief of 60 mm (2.2 in) diameter gave the largest increments. Figure 9 shows graphically the effect of relief on MESG for all flange breadths in vented and unvented explosions.

The variations caused by the reliefs were marginal with the largest relief, and with flanges of small breadth reductions of MESG occurred; these explosions were usually accompanied by vibration superimposed on the time-pressure trace (Fig. 10a). Figure 10b shows a typical pressure record where there were no vibrations.

The effects of change in ignition position

The results obtained from experiments using various ignition positions are given in Table 3. It can be seen that the ignition position near the gap and near the flame arrester produced the smallest MESG. Ignition in the centre of the vessel produced much less severe conditions.

The effect of various obstacles

Although the results (Table 4) are not complete it can be seen that the obstacles used had virtually no effect upon the MESG. There was, however, a marked increase in the maximum explosion pressure, particularly with the 90 per cent orifice plate positioned in the middle of the vessel.

DISCUSSION

Basic mechanism

There was a great deal of work carried out in the past on the measurement of MESG[3,4,5,6]. This was carried out with unvented vessels and flange breadths ranging from 6 mm to 37 mm. Much of the results were incorporated into various national standards[7]. The mechanism of explosion transmission through such flanges was largely elucidated and it is generally accepted that with gaps smaller than the quenching distance but larger than the MESG, the mechanism of explosion transmission is by ignition of unreacted flammable mixture residing near the gap by emerging hot combustion products. Before the flame reaction can be initiated, various conditions must be satisfied. Thus the emerging hot combustion products must be at or above the required temperature; they must also during the brief contact with the unreacted gas supply enough heat to start a self-supporting flame reaction. The photographic evidence indicates that the flame reaction starts in the region of eddies formed by the decelerating section of the hot stream of combustion products[5]. With non-vented explosion vessels the most critical conditions are created by low rates of pressure rise and subsequent low velocity of emerging combustion products, these facilitating the ignition. This explanation has been treated theoretically by Phillips who derived an ignition model based on fundamental properties of the reactions and the dimensions of the gap. Using this model, the MESG of many gases can be calculated with good accuracy[8].

Comparison with other results

The values of MESG of 25 mm (1 in) breadth obtained in this investigation are 0.025 mm (0.001 in) wider than those quoted in reference[6]. In current unpublished work with hydrogen-air mixtures the MESG was again wider by 0.025 mm than the value quoted in reference[6]. The uniformity of this discrepancy suggests that it may be caused by differences in experimental technique. For instance, the shape of the vessel was cylindrical whereas in other relevant investigations spherical vessels were used.

The continuing work with explosion reliefs indicates that they may create conditions leading to an increase in the MESG[9]. This is probably caused by increased rates of pressure rise, created by disturbances in the unburnt gas flowing through the arrester. For this to happen, the disturbance must occur in the early stages of the explosion. Increases in the rate of pressure rise caused by obstacles were too late to have any effect.

TABLE 1

Results of maximum experimental gap determinations without venting using various flange breadths

Flame breadth		Flammable gas	Experimental gap		No. of tests	No. of trans-missions	Maximum pressure	
mm	(inches)		mm	(1/1000) (inches)			kN/m^2	(lbf/in^2)
25.4	(1.0)	Propane	1.04	41	10	7	41	6
			1.02	40	10	2	48	7
			0.99	39	20	0	52	7.5
		Ethylene	0.76	30	5	5	310	45
			0.74	29	20	0	338	49
			0.71	28	10	0	332	48
12.7	($\frac{1}{2}$)	Propane	0.91	36	3	1	90	13
			0.89	35	15	2	97	14
			0.86	34	20	0	104	15
		Ethylene	0.66	26	2	1	345	50
			0.61	24	13	1	345	50
			0.58	23	20	0	360	52
6.4	($\frac{1}{4}$)	Propane	0.76	30	5	3	173	25
			0.74	29	20	0	180	26
		Ethylene	0.53	21	2	1	455	66
			0.51	20	20	0	470	68
			0.48	19	5	0	470	68
3.2	($\frac{1}{8}$)	Propane	0.64	25	5	1	235	34
			0.61	24	20	0	242	35
		Ethylene	0.46	18	2	2	483	70
			0.43	17	5	2	517	75
			0.41	16	20	0	535	77.5
1.6	($^1/16$)	Propane	0.61	24	5	1	207	30
			0.58	23	20	0	200	29
		Ethylene	0.43	17	5	5	447	65
			0.41	16	7	2	447	65
			0.38	15	20	0	470	68

TABLE 2

Results of maximum experimental gap determinations with venting using various flange breadths

Flange breadth		Arrester diameter		Flammable gas	Experimental gap		No. of tests	No. of transmissions	Maximum pressure	
mm	(in)	mm	(in)		mm	(^{1}/1000 in)			kN/m^2	lbf/in^2
25.4	(1)	29	(1.15)	Propane	1.09	43	10	6	14	2.0
					1.07	42	10	1	15	2.1
					1.04	41	20	0	15	2.1
				Ethylene	0.77	30.5	10	7	125	18.0
					0.75	29.5	20	0	130	19.0
25.4	(1)	57.5	(2.25)	Propane	1.09	43	6	6	10	1.5
					1.08	42.5	10	2	10	1.5
					1.07	42	20	0	10	1.5
				Ethylene	0.77	30.5	10	4	17	2.5
					0.76	30	20	0	17	2.5
25.4	(1)	110	(4.3)	Propane	1.09	43	10	6	3.5	0.5
					1.07	42	20	1	7	1.0
					1.04	41	20	0	7	1.0
				Ethylene	0.77	30.5	4	4	10	1.5
					0.75	29.5	17	2	10	1.5
					0.74	29	20	0	10	1.5
12.7	(½)	110	(4.3)	Propane	0.89	35	3	2	5.5	0.8
					0.86	34	18	1	1.5	0.2
					0.85	33.5	20	0	1.5	0.2
				Ethylene	0.66	26	2	2	1.5	0.2
					0.63	25	20	0	1.5	0.2

TABLE 2 cont'd

Flange breadth		Arrester diameter		Flammable gas	Experimental gap		No. of tests	No. of transmissions	Maximum pressure	
mm	(in)	mm	(in)		mm	(^{1}/1000 in)			kN/m^2	lbf/in^2
3.2	($\frac{1}{8}$)	29	(1.15)	Propane	0.68	27	2	2	95	14.0
					0.66	26	6	1	100	14.5
					0.63	25	20	0	105	15.0
				Ethylene	0.51	20	3	2	333	48.0
					0.49	19	5	1	360	52.0
					0.46	18	20	0	380	55.0
3.2	($\frac{1}{8}$)	110	(4.3)	Propane	0.61	24	3	3	7	1.0
					0.58	23	20	0	3	0.4
				Ethylene	0.46	18	2	1	7	1.0
					0.43	17	20	0	4	0.6
1.6	(^{1}/16)	29	(1.15)	Propane	0.58	23	7	2	90	13.0
					0.56	22	20	0	97	14.0
				Ethylene	0.41	16	4	4	400	58.0
					0.38	15	20	0	400	58.0
1.6	(^{1}/16)	110	(4.3)	Propane	0.56	22	8	2	1.58	0.2
					0.53	21	5	2	1.65	0.2
					0.51	20	20	0	1.86	0.3
				Ethylene	0.41	16	2	2	34.5	5.0
					0.38	15	2	2	13.8	2.0
					0.36	14	20	0	6.9	1.0
1.6	(^{1}/16)	57.5	(2.25)	Propane	0.58	23	2	2	14	2.0
					0.56	22	16	8	9.0	1.3
					0.53	21	20	0	9.0	1.3
				Ethylene	0.41	16	2	2	38	5.5
					0.38	15	20	0	35	5.0

TABLE 3

Results of gap determinations with alternative ignition position

Flange breadth 25 mm (1 in)

Flame arrester diameter		Flammable gas	Ignition position	Experimental gap		No. of tests	No. of trans-missions	Maximum pressure	
mm	in.			mm	$^1/1000$ in.			kN/m^2	lbf/in^2
No arrester		Propane	Centre of vessel	1.93	76	4	2	29	4.2
				1.90	75	6	1	28	4.1
				1.88	74	20	0	29	4.2
29	1.15	Propane	Centre of vessel	1.85	73	3	2	16.5	2.4
				1.83	72	3	1	18	2.6
				1.80	71	20	0	18	2.6
110	4.3	Propane	10 mm below arrester	1.09	43	10	6	3.5	0.5
				1.07	42	20	1	7	1
				1.04	41	20	0	7	1
110	4.3	Ethylene	10 mm below arrester	0.75	29.5	5	2	11	1.6
				0.74	29.0	4	1	12.5	1.8
				0.72	28.5	20	0	11	1.6

TABLE 4

The effects of various obstacles on the maximum experimental safe gap based on ten tests

Flange breadth 25 mm (1 in)

Area blocked	Position of obstacle below gap		Maximum pressure		M.E.S.G.	
per cent	mm	in.	kN/m^2	lbf/in^2	mm	$^1/_{1000}$ in.
None	–	–	41	6.0	0.99	(39)
50	40	1.8	41	6.0	0.99 - 1.02	(39-40)
50	108	4.3	45	6.5	1.04 - 1.07	(41-42)
50	152	6.0	52	7.5	1.02	(40)
90	40	1.8	23	3.3	1.04 - 1.07	(41-42)
90	108	4.3	165	24	0.99 - 1.02	(39-40)
90	152	6.0	117	17	0.99 - 1.02	(39-40)

These determinations were carried out in steps of 0.05 mm (0.002 in)

The small reductions in MESG experienced in the presence of acoustic vibrations indicate a different mechanism of transmission. This transmission occurs long after ignition, and when acoustic waves reach their highest amplitude. This mechanism cannot be explained without some additional measurements. It is clear, however, that during the oscillations substantial movements of gas occur, accompanied by variation in the combustion rate. Results obtained with the igniting source near the arrester show that the insertion of the vent creates conditions where there may be several positions of the igniting source producing the smallest MESG. This may also be caused by the modification of the initial rate of pressure rise. The phenomenon needs further investigation.

Practical applications

The experimental system described in this paper has been designed to simulate practical conditions, envisaged in industrial equipment where the arrester will be mounted in the lid and this will incorporate some form of peripheral closure[1,2]. It has been shown that with such geometry no decrease in the MESG is to be expected.

These findings indicate that under the most severe conditions, the relief does not have unfavourable effects in the early part of the explosion. Subsequent changes that may occur in the pressure/time relationship are too late to have any effect. The values of MESG obtained with flanges of narrow breadth are substantial enough to be used with equipment provided with large area reliefs.

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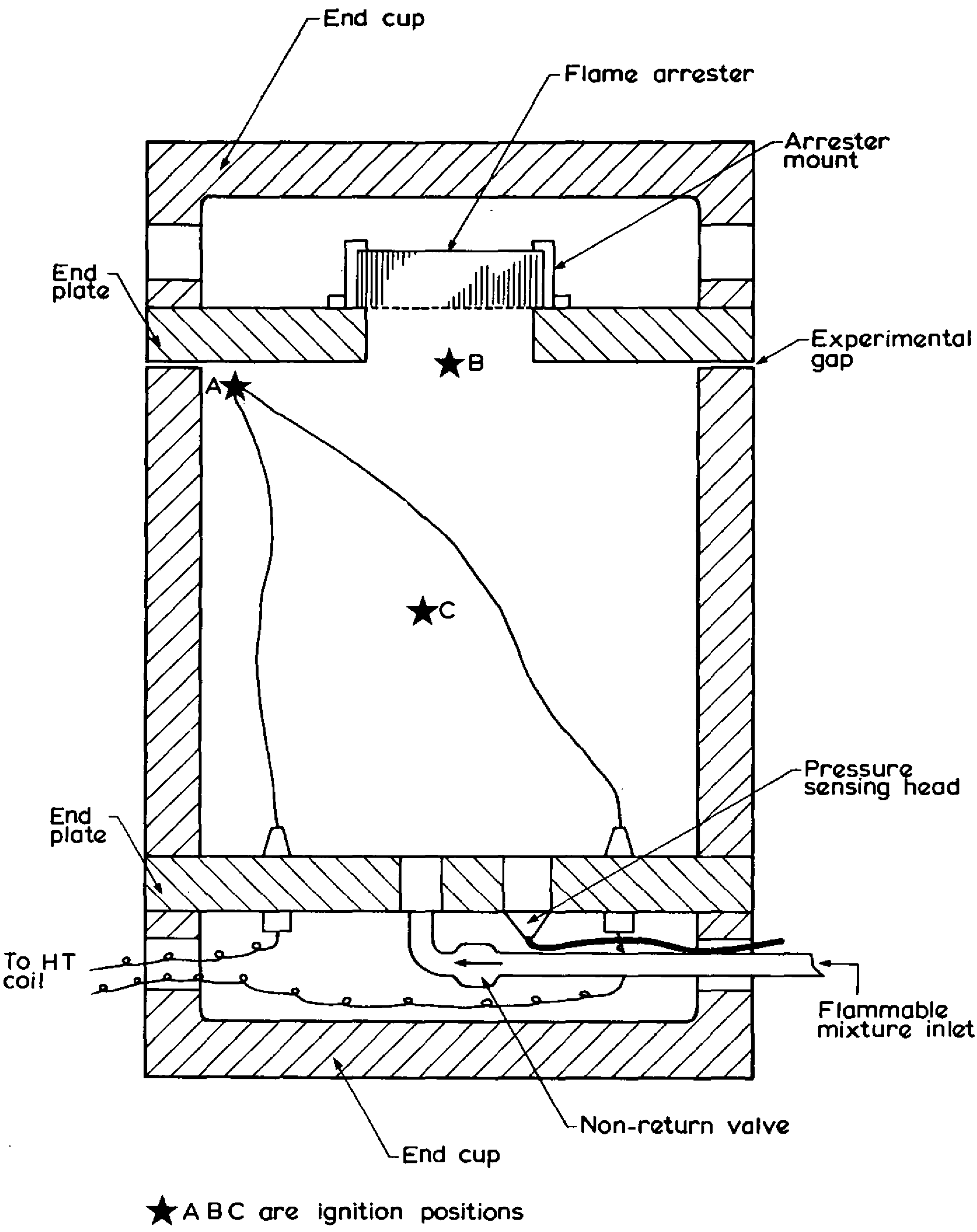


Figure 1 Cross-sectional view of the explosion vessel

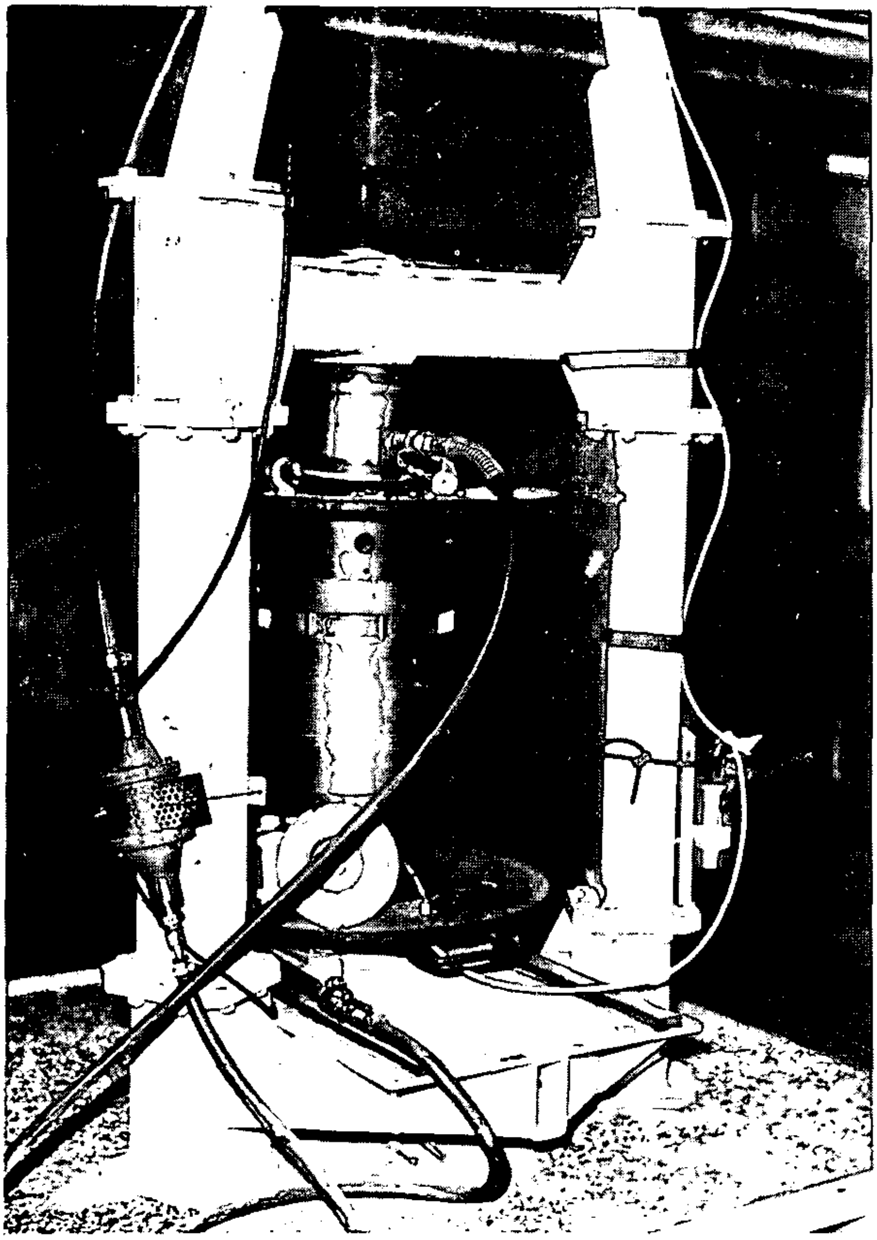


FIG. 2. TEST VESSEL ASSEMBLED IN PRESS

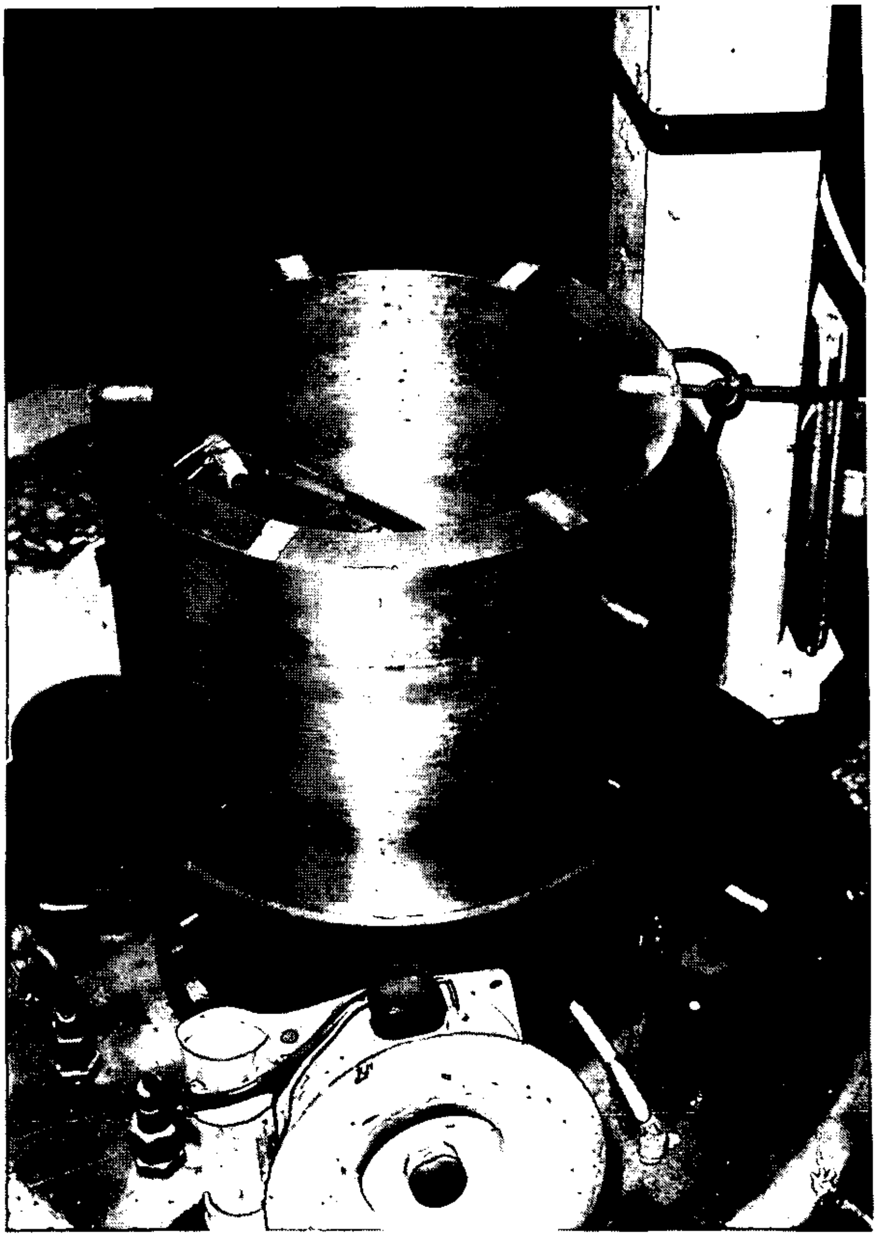


FIG. 3. TEST VESSEL WITH LID REMOVED SHOWING SIX SPACER SKIMS AND IGNITION ELECTRODES

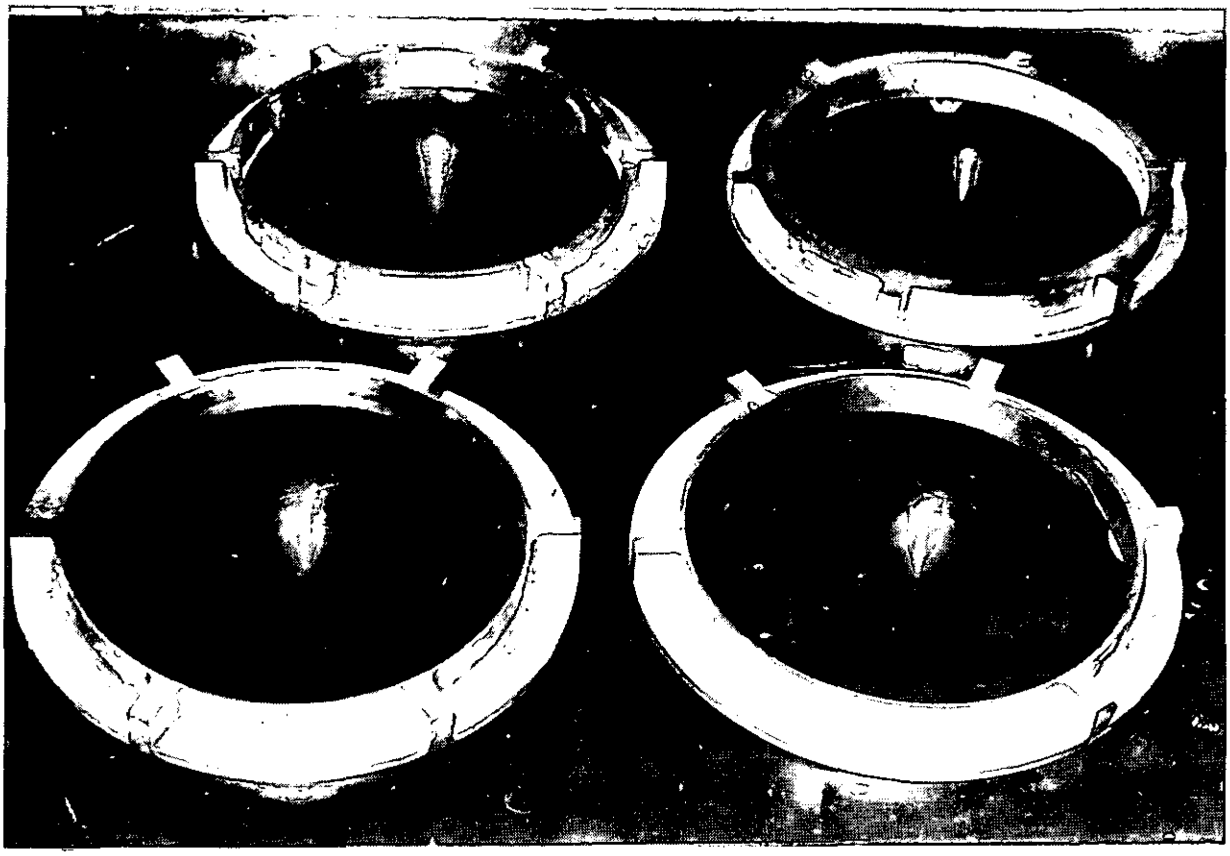


FIG. 4. ADAPTOR RINGS FOR FLANGE BREADTHS LESS THAN 25 MM (1 IN)

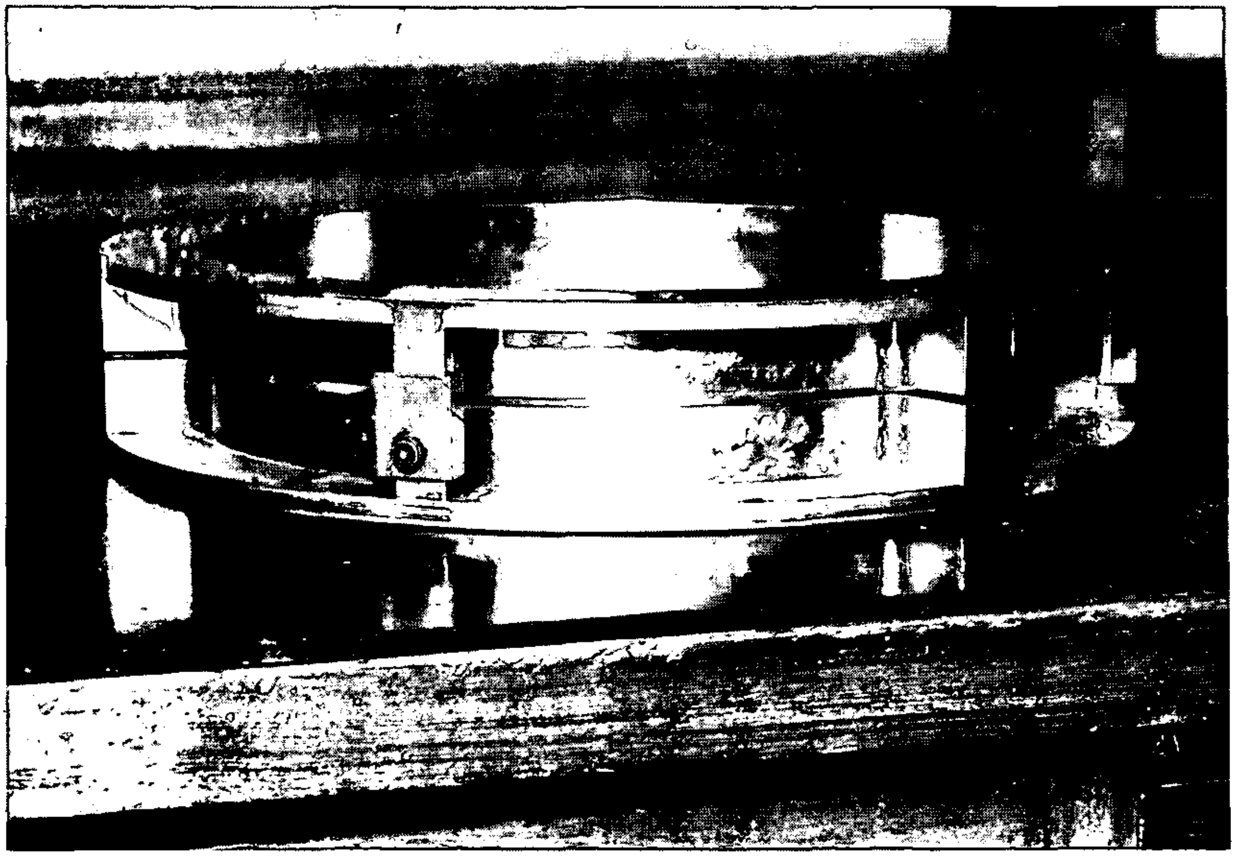
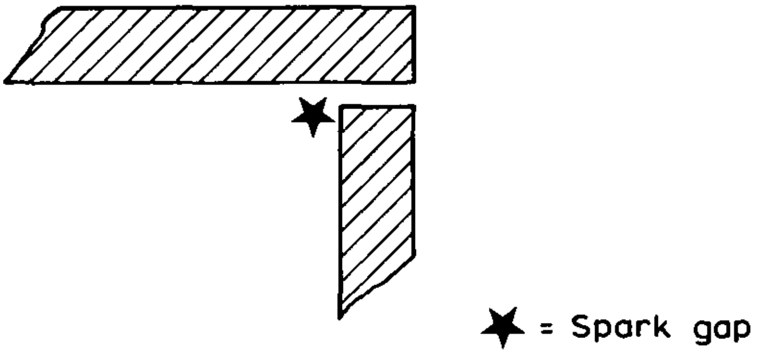
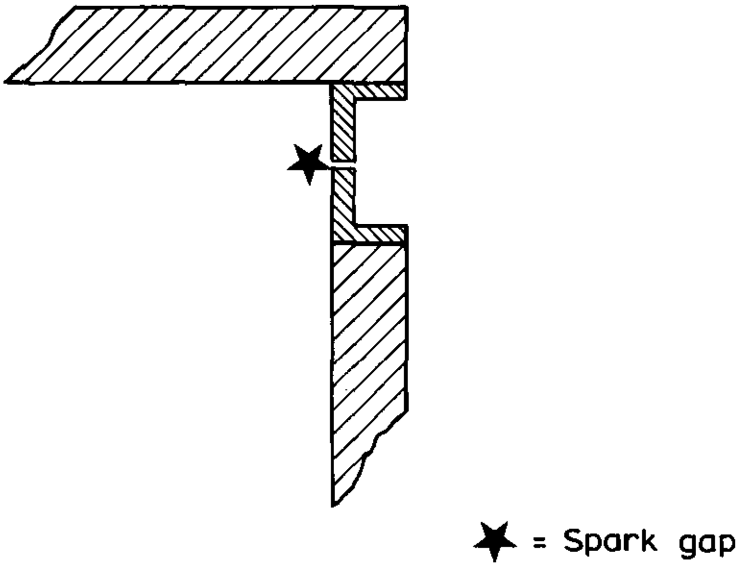


FIG. 5. FLANGE LOCATING DEVICE FOR THE 1.6 MM (1/16 IN) RINGS



Arrangement of gaps for 25mm (1 in) flange breadth



Arrangement of gaps and ignition for 12·7mm ($^{1}/_{2}$in) to 1·59mm ($^{1}/_{16}$in) flange breadth

Figure 6 Position of ignition electrode relative to gap

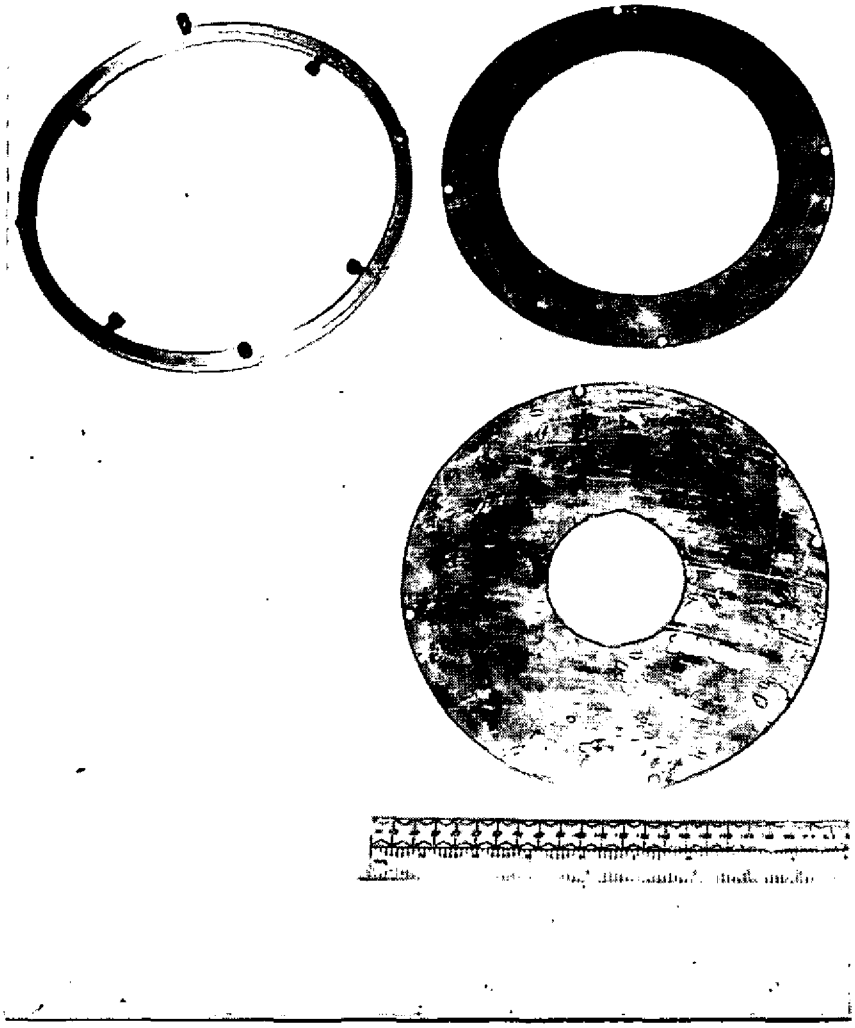


FIG. 7. ORIFICE PLATES AND RETAINING RING

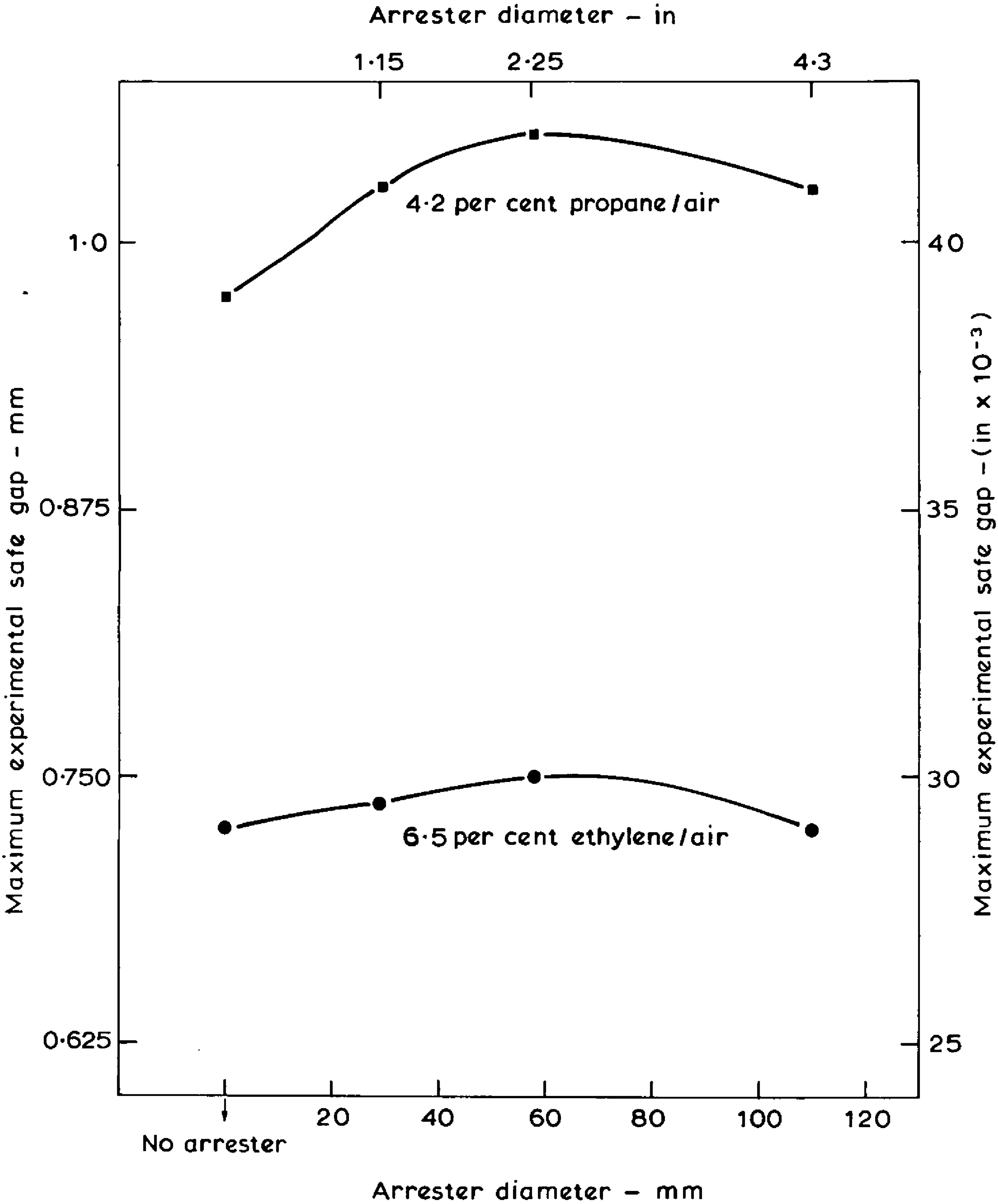


Figure 8 The effect of arrester diameter on maximum safe gap for 25mm (1in) flange breadth

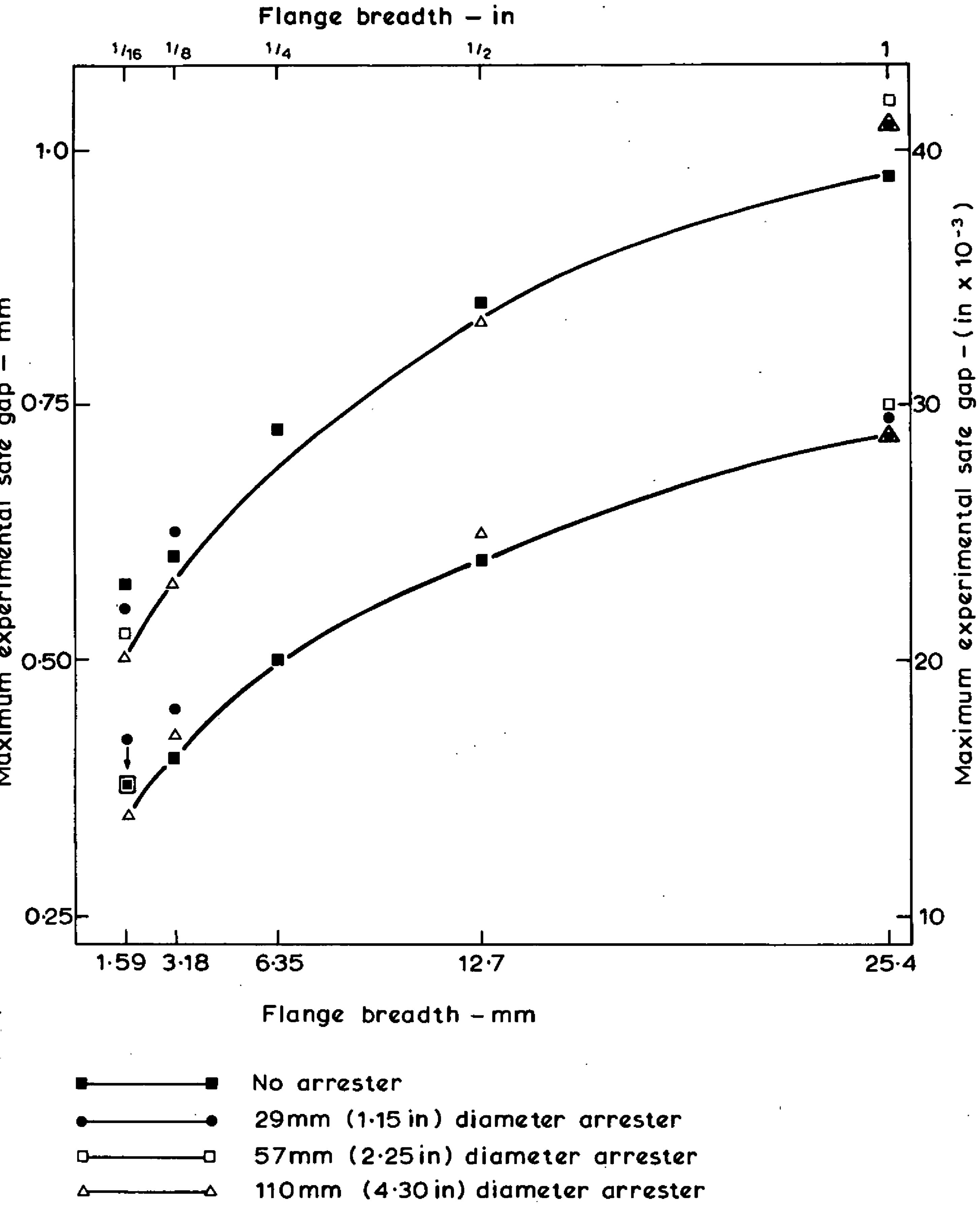
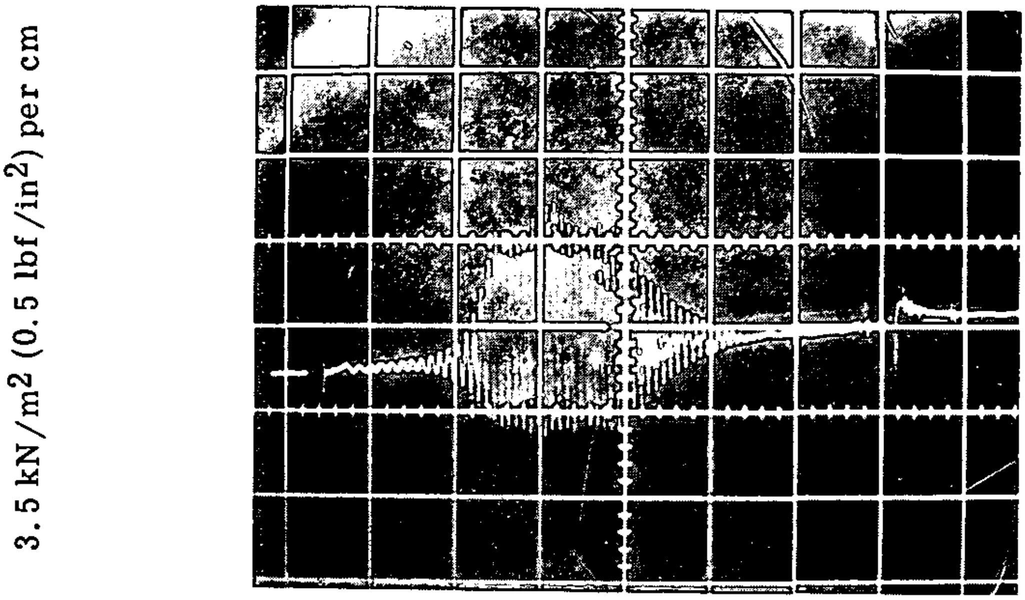
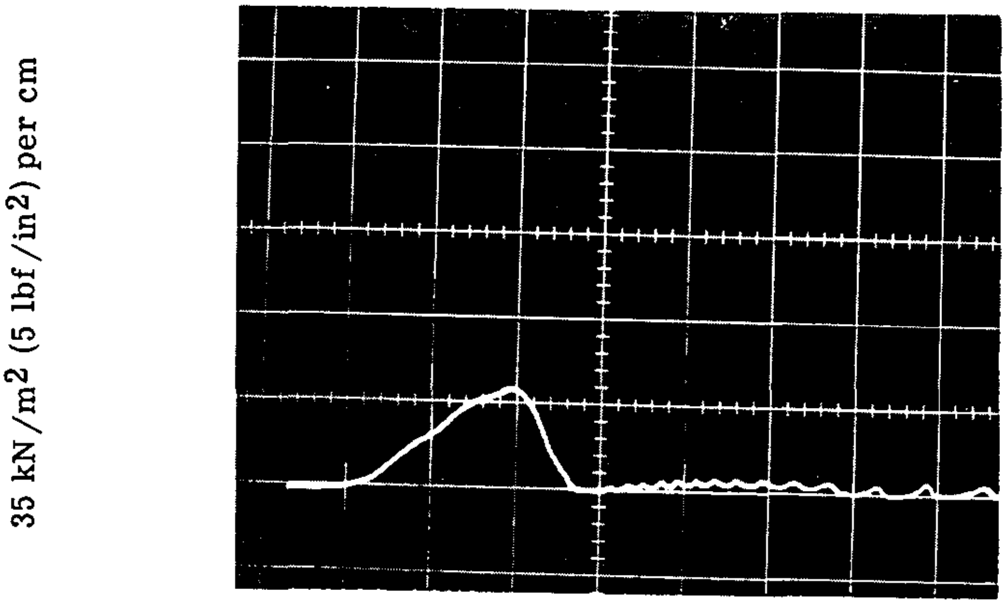


Figure 9 The effect of flange breadth on maximum experimental safe gap



(a) Pressure trace showing acoustic oscillations 50 m sec/cm



(b) Typical pressure trace 50 m sec/cm

FIG. 10. SPECIMEN PRESSURE RECORDS

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by Rome Printers London W13 8PR from copy supplied