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PERFORMANCE OF METALLIC FOAM AS A FLAME ARRESTER

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SUMMARY

New metallic material resembling a structure of a sponge was investigated for application as a flame arrester. Its performance as a flame arrester in a tube was promising. Various grades were tested up to flame speeds of 200 m/s (600 ft/s) and with materials having similar resistance to air flow as commercial flame arresters no transmission of flame occurred.

KEY WORDS: Flame arrester, foams metallic

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INTRODUCTION

Flame arresters have a number of traditional uses in industrial plants and various constructions of arrester are being used. Examples are: crimped ribbon arresters, arresters constructed from compressed knitted wire fabric, wire gauze, raschig ring, and gravel arresters. All these structures have their special applications.

Recently a new material, 'Retimet', was developed by Dunlop Co Ltd; this has certain characteristics indicating its suitability for use as a flame arrester. This new material is a metallic structure resembling sponge, having uniform interconnecting cavities. It can be manufactured from various metals and alloys and the size of pores may be varied. It was obvious that such a structure might give very good performance as a flame arrester. The object of this paper is to provide an evaluation of flame arresting abilities of this material.

APPARATUS

A perspex tube 6.3 cm (2.5 in) diameter was used to obtain a moving flame front. Figure 1 shows the diagram of the apparatus. Various lengths of perspex tube were connected with mild steel sockets to give the required length of tube. Each socket had provision for insertion of a pressure measuring transducer. One end of this tube was left open and the other closed with a blank flange. The igniting source was located near the closed end, 129 cm (51 in) upstream from the arrester. The arresters were mounted at point 'C' with a further 147 cm (58 in) of tube terminating in an open end. In order to increase the flame speed in some tests a spiral made out of 6 mm ($\frac{1}{4}$ in) diameter tube was inserted in various positions between igniting source and the arrester.

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PRESSURE MEASURING APPARATUS

Figure 2 shows the block diagram of the measuring apparatus. In all experiments the maximum explosion pressures were measured using quartz transducers. Transducers were usually situated either near the igniting source or 36 cm (14 in) upstream from the arresters. (In a few tests pressures downstream the arresters were also measured). In some tests pressure was measured in these two positions simultaneously. The time-pressure curves were recorded by photographing the screen of the oscilloscope.

FLAME SPEED MEASUREMENT

During each explosion sections of perspex tube upstream and downstream the arresters were photographed on a revolving drum camera (see Fig.2). Simultaneously, timing marks were inserted on the photographic paper. In addition there was an ionisation gap detector near the open end of the tube which signalled the arrival of the flame at the open end. In some tests the arrival of the flame at the arrester was also timed. This ensured that the maximum explosion pressure within the tube was measured while the flame was in contact with the arrester or was being quenched within the arrester apertures.

ARRESTERS

The material tested was of cellular nature. Figure 3 shows the photograph of a specimen. Its structure may be best described as a network formed of hollow spheres which have several sections removed, thus bearing a number of perforations in each cell separated by narrow ribs. Such structures when cut leave a number of holes of diameter equal to or less than the diameter of the cell on the surface of the arrester. There is a large variation in size of the pores and, even if the size of smaller perforations are measured, these may vary greatly. In this report nominal porosities given by the manufacturer are quoted. These were derived by the manufacturer, and all nominal porosities quoted are based on such determinations. All arresters tested were of homogeneous structure with the exception of one arrester of composite structure. This consisted of two layers of different Retimet cement together. Table 1 describes details of arresters used.

Table 1

Details of arresters tested

Porosity	Thickness	
Nominal pores/in	cm	in
10	2.5	1.0
20	2.5	1.0
20	1.25	0.5
45	1.25	0.5
80	0.6	0.25

The composite structure arrester consisted of one layer 2.5 cm (0.10 in) thick 10 pore layer attached to 0.36 cm ($\frac{1}{8}$ in) thick 80 pore layer. In all tests the 80 pore layer faced the flame front. All arresters were made from nickel chrome, with the exception of that of nominal porosity 80 which was annealed nickel.

IGNITION

The gases were ignited by an inductive spark delivered from a 12 v car induction coil, across a 1 mm gap, see Fig.2.

FLAMMABLE GASES

In a few tests 4.2 per cent propane-air mixture was used, but in the majority of tests higher flame speeds were required and 6.5 per cent ethylene-air mixture was used.

PROCEDURE

The explosion tube was filled with the explosive mixture by displacement of air, and at the time of ignition the mixture was stationary. While the explosion was proceeding, streak photographs of the flame and pressure records were obtained simultaneously. If the flame penetrated the arrester, its arrival at the open end of the tube was also detected and recorded with the air of ionisation gap signalling the arrival of the most advanced portion of the flame front.

RESULTS

Figure 4 shows the flame speeds generated within the tube with various porosity arresters. Some flame penetrations were obtained with arresters of porosity 10 and 20. With arresters of porosity of 20, flame was transmitted at very similar velocities for both 2.5 cm (1 in) and 1.2 cm ($\frac{1}{2}$ in) thick Retimet. Figure 5 shows the drum camera flame trace with a nominal 10 pore arrester of thickness 2.5 cm (1 in). Point A indicates the position of the arrester, and point B indicates re-ignition of the flammable mixture downstream of the attester. The flammable mixture used in this test was 6.5 per cent ethylene in air. Figure 6 shows the drum camera flame trace with 45 pore arrester of 1.2 cm ($\frac{1}{2}$ in) thickness using 6.5 per cent ethylene-air mixture. In this test the arrester stopped the flame.

Figure 7 shows a specimen of explosion and ionisation gap record, with the spiral situated 30 cm (12 in) away from the igniting source. Deflection shown by the trace marked a indicates the arrival of the flame front at the arrester, Trace b shows the explosion pressure recorded near the igniting source. Trace c shows the explosion pressure recorded by the gauge situated near the arrester.

Evidently there is a small pressure drop along the pipe, the gauge situated near the arrester recording a slightly higher maximum pressure. Points B marked on both pressure traces indicate rapidly increasing rate of pressure rise, and this was caused by the interaction of the flame and the turbulence generated by the spiral. After a further few milliseconds the maximum explosion pressure near the arrester attained the value of 350 kN/m^2 (50 lb/in^2). This was followed by a period of large amplitude pressure vibration. The maximum pressure near the ignition source (trace b) was somewhat lower than that recorded near the arrester and many of the vibrations merged to give a single peak.

Figure 8 shows the maximum explosion pressures recorded on downstream and upstream sides of the arrester, traces b and c respectively. Trace a indicates the arrival of the flame front at the arrester. There is a considerable pressure drop across the arrester and some of the transient peaks merged after penetration of the arrester.

Figure 9 shows the ionisation gap and the pressure traces obtained with a 20 nominal pores arrester 2.5 cm (1 in) thick, in a tube with no spiral; traces b and c measure the pressure near the arrester and the ignition source respectively, using 6.5 per cent ethylene-air mixture. Traces show there is no pressure drop along the tube, rates of pressure rise are much lower than in tests with the spiral and there are no vibrations.

Table 2 gives the ranges of the maximum explosion pressure recorded near the arrester, also the explosion pressures with the vibrations of less than 5 m/sec excluded are given.

DISCUSSION

There has been a great deal of research carried out on the performance of flame arresters in various tubes. Palmer[1] formulated a theory explaining the flame quenching in terms of heat loss to the wall of the arrester apertures. This theory assumes that the flame is quenched by cooling. The maximum safe flame speed may be correlated with the diameter and length of the apertures in the arrester by

$$V = 0.95\ ny\ po/_p \qquad \ldots\ldots (1)$$

where V is the flame speed (ms^{-1})

n is the number of apertures in unit area of arrester surface (cm^{-2})

po atmospheric pressure

p explosion pressure (absolute) when the flame reaches the arrester

y is the thickness of the arrester (cm).

This equation was valid for various flame arresters whose apertures were not more than half as wide as the quenching diameter of the gas mixture. For propane/air and ethylene/air, of the compositions used in the present work, the quenching diameters are 3.0 and 1.8 mm respectively.

In Fig.10 the flame speed V is plotted against $ny\ po/_p$; equation (1) is shown as a full line over its expected range of validity and as a broken line for larger pore diameters.

The equation, and the full line representing it in Fig.10, may be used to compare the performance of the Retimet flame arresters with the traditional types. For the latter, flames with speeds below the line are quenched and faster flames, above the line, pass through the arrester. With Retimet there is some uncertainty as to the values for n, but if they are based directly on the nominal porosities, equation (1) would tend to underestimate the performance of the Retimet. The behaviour of the arresters of nominal porosity 20 cannot be compared likewise because the pore diameter is such that equation (1) would not be valid. For finer pores the performance of the Retimet is at least as effective, and possibly more so, in quenching flames than would be expected from the equation and the traditional types of arrester.

The mechanism of transmission appears to be the penetration of hot combustion products through the arrester apertures and re-ignition occurs downstream the arrester. The combustion starts in very small volume, which grows until it occupies the cross sectional area of the tube. For such re-ignition to occur, the hot combustion products must contact or mix with the unburnt gas and yet maintain the temperature required for the ignition.

The penetration of arrester occurred at the pressures well above ambient, this making the duties of the arresters more arduous. When such pressures are defined, it is probably more correct to consider the pressures with the transients excluded.

The use of an explosion tube with a spiral obstacle creating disturbances in the unburnt gas, offers some advantages. Thus very high flame speeds may be obtained in a relatively short tube. These disturbances, however, make the combustion process more complicated. Both the pressure record and the flame movement record show the effects of pressure waves created by the presence of such obstacles. Thus the pressure records may show a number of transient peaks and the flame front may be either accelerated or decelerated by such waves, as a result localised pressure gradients along the pipe are evident, making the interpretation of results more difficult. The pressure record shown in Fig.7 illustrates this point. After ignition there is a relatively low rate of pressure rise until the flame front begins to interact with the turbulence created by the spiral in the unburnt mixture. This results in a very rapid rate of pressure rise shown by both gauges. This is followed by a number of pressure waves, one of those reaching the value of 78 kN/m^2 (114 lb/in). There is a considerable pressure drop near ignition source and merging of some waves is evident following the arrival of the flame at the arrester.

PRACTICAL APPLICATION

The Retimet performs well as a flame arrester and it is no worse than crimped ribbon of similar aperture. With present apparatus it was only possible to test coarser grades until failure. The finer grades stopped flames with speeds in excess of 200 m/s (600 ft/s) with no signs of thermal damage. The 80 porosity 7 mm ($\frac{1}{4}$ in) thick arrester was found at the completion of tests to be dished.

Retimet can be cut readily to obtain a variety of shapes, and it is possible that it can be mounted with little extra expenditure.

In practice finer grades will have to be used; for present purposes use of Retimet arresters of porosity 10 is ruled out as it has too low safety margin, and arresters of porosity 20 would have limited application.

REFERENCES

1. PALMER, K. N. and TONKIN, P. S. Chemical Process Hazards 1963 (London : The Institution of Chemical Engineers).

Table 2

Maximum pressure ranges obtained with various arresters

Nominal porosity	Thickness		Flammable gas	Maximum pressure range			
				With transients		Without transients*	
	cm	(in)		kN/m^2	lbf/in^2	kN/m^2	lbf/in^2
20	2.5	(1.0)	Propane	45-168	65-24	49-98	7-14
20	2.5	(1.0)	Ethylene	140-280	20-40	42-175	6-25
45	1.3	(0.5)	Propane	42	6	42	6
45	1.3	(0.5)	Ethylene	84-940	12-133	56-266	8-38
80	0.6	(0.25)	Propane	267-280	38-40	252	36
80	0.6	(0.25)	Ethylene	525-735	75-105	175-259	25-37
10/80	2.9	(1.13)	Propane	42-91	6-13	28-595	4-85
10/80	2.9	(1.13)	Ethylene	42-175	6-25	21-105	3-15

*See text

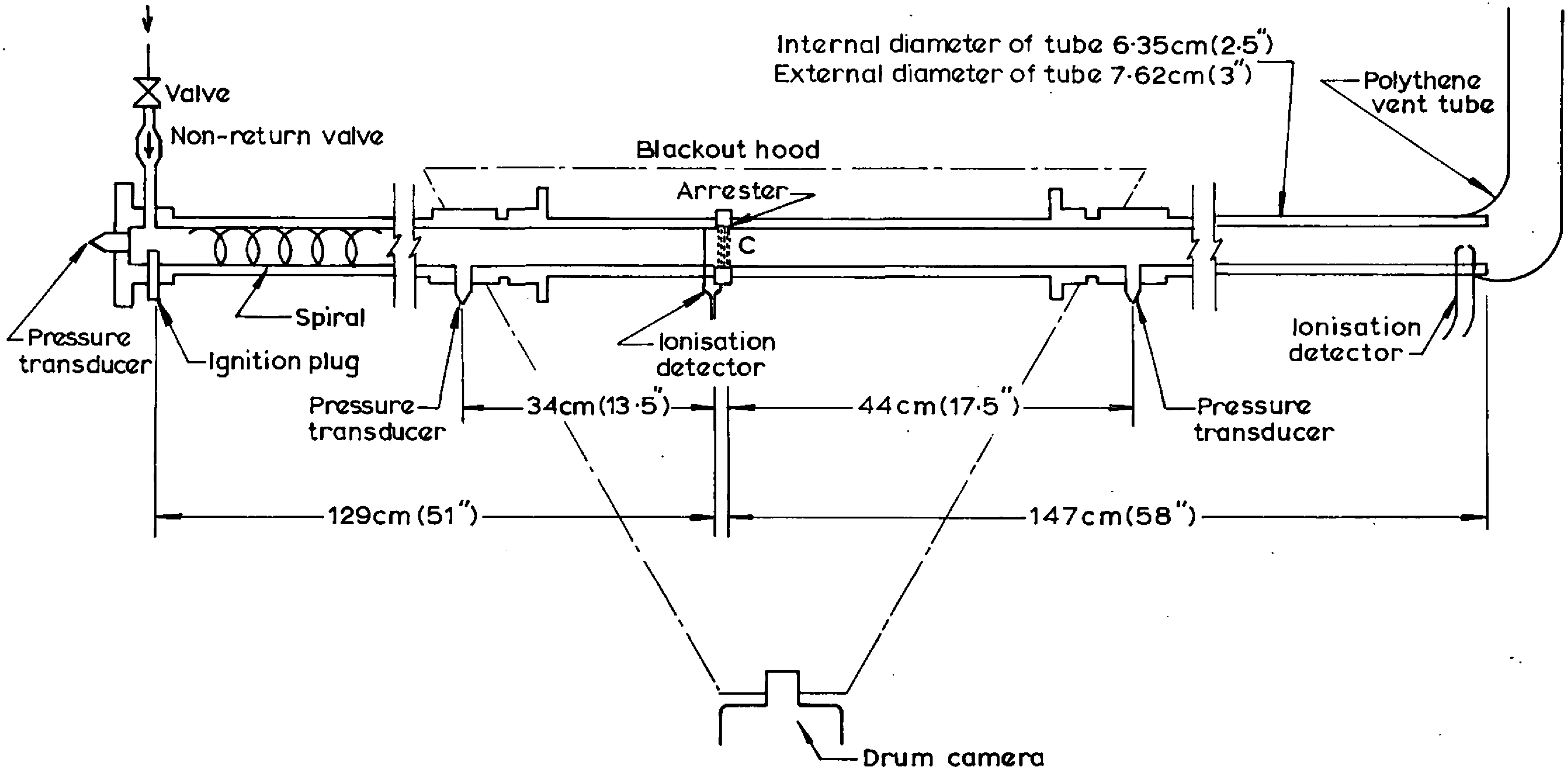


FIG.1 DIAGRAM OF THE APPARATUS

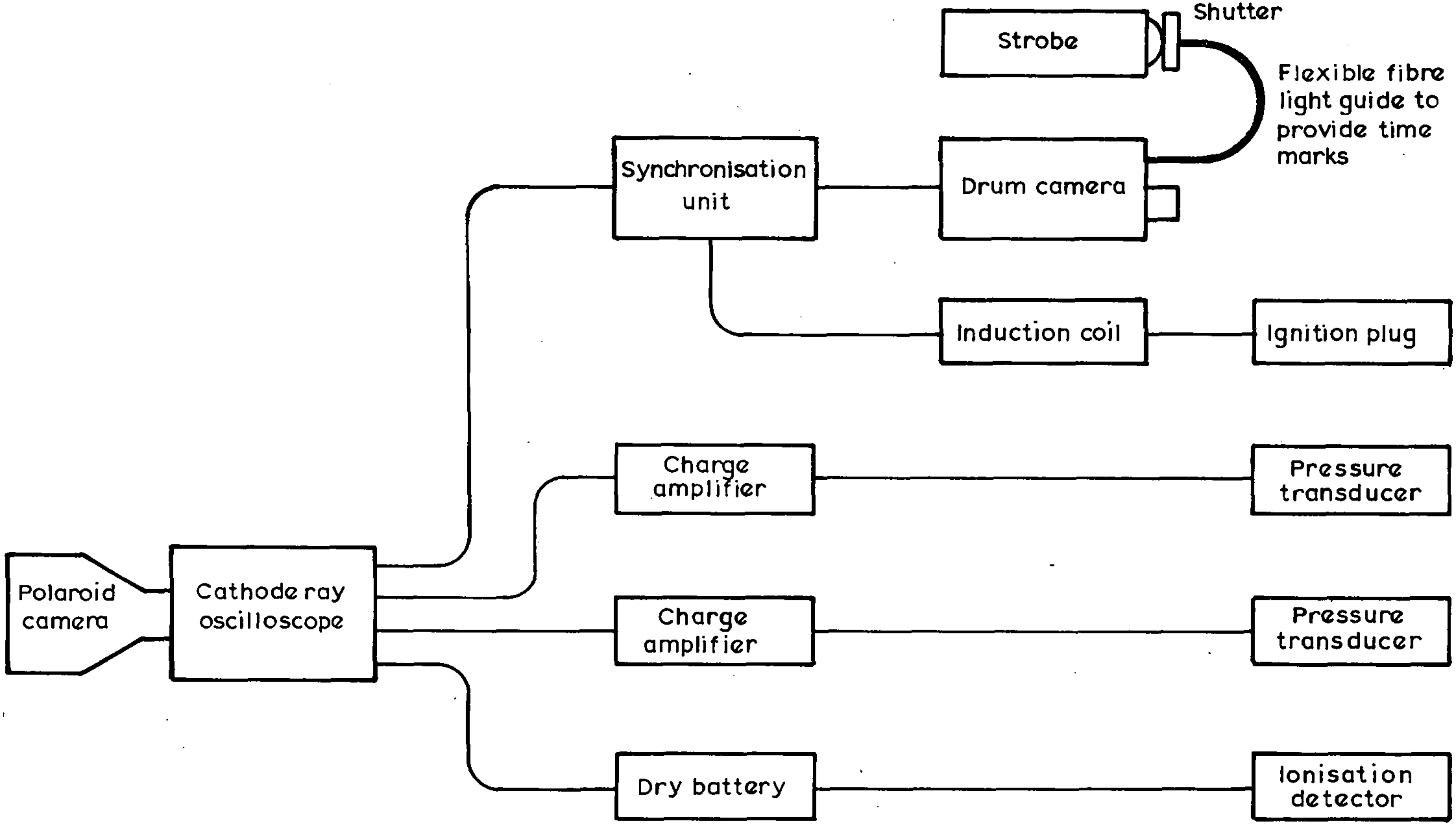


FIG.2 BLOCK DIAGRAM OF APPARATUS

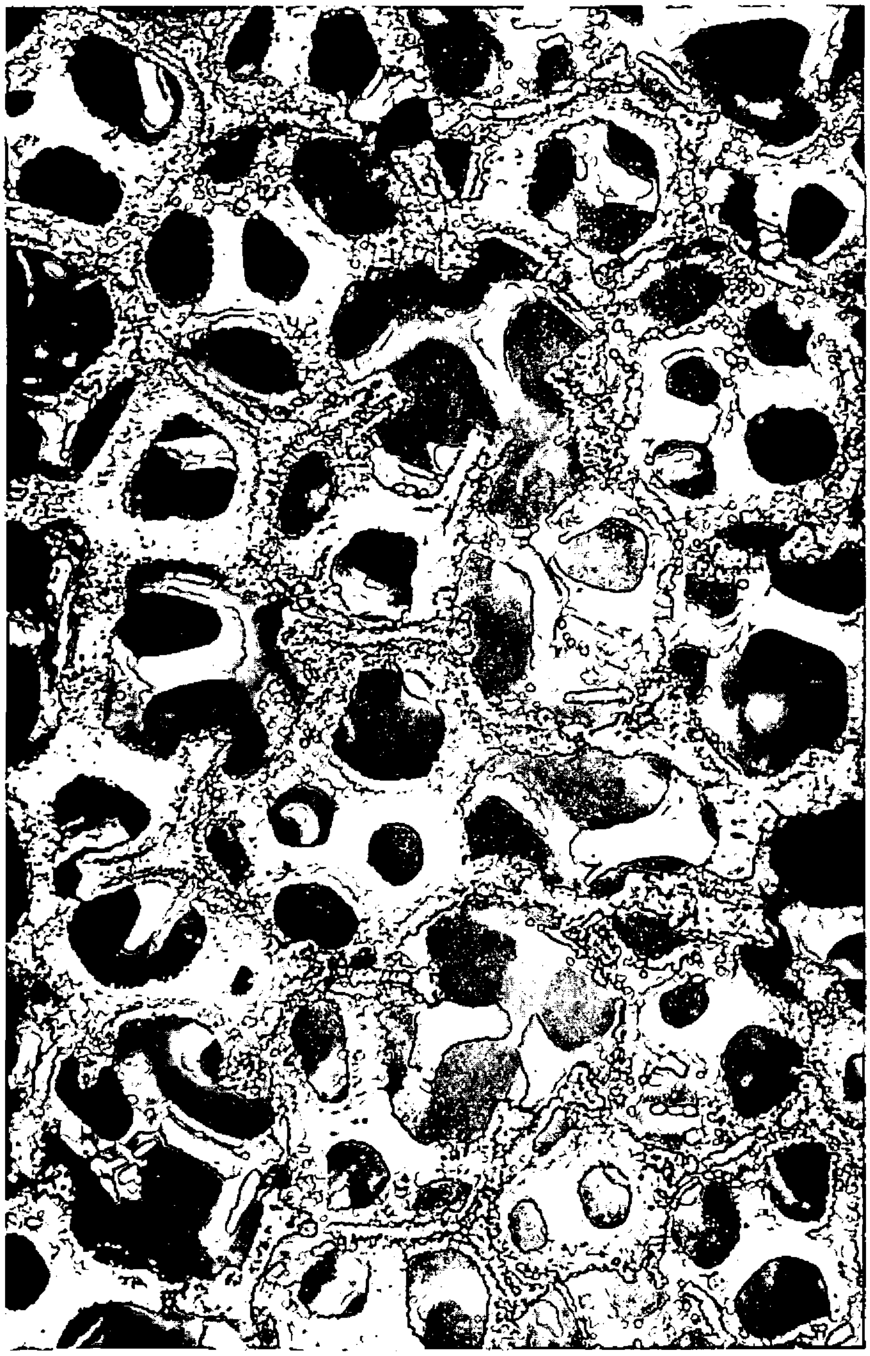


FIG.3 RETIMET ARRESTER MAGNIFICATION 10

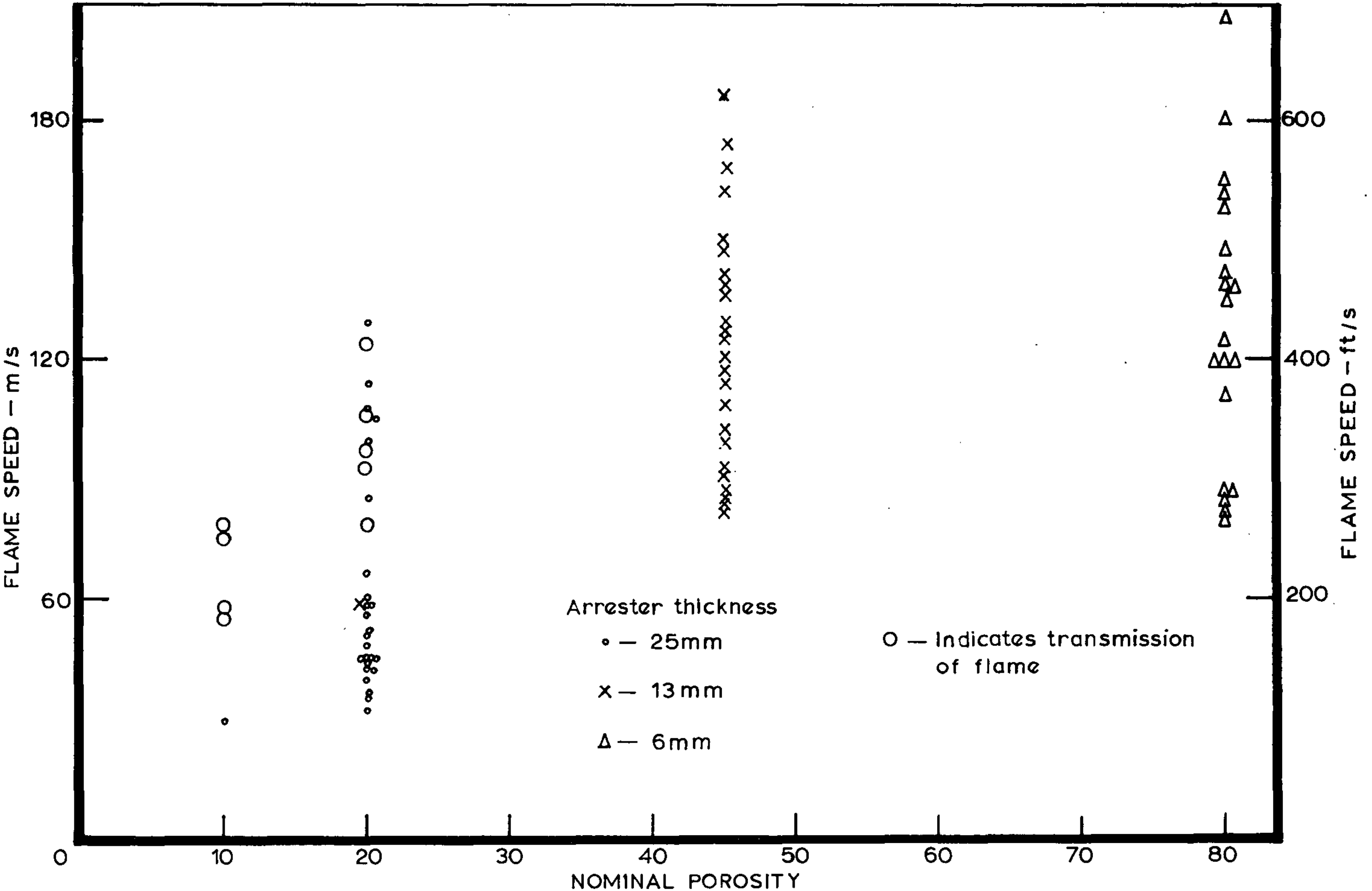
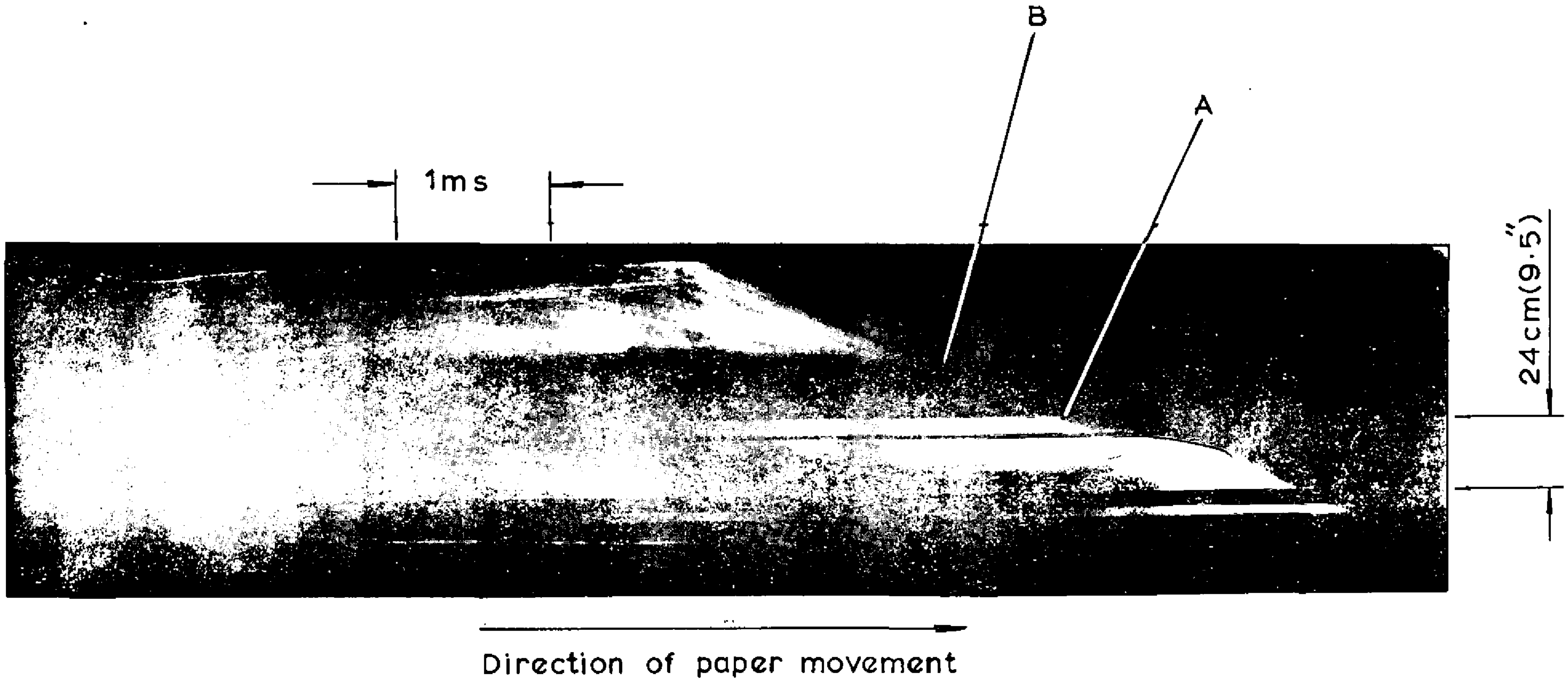
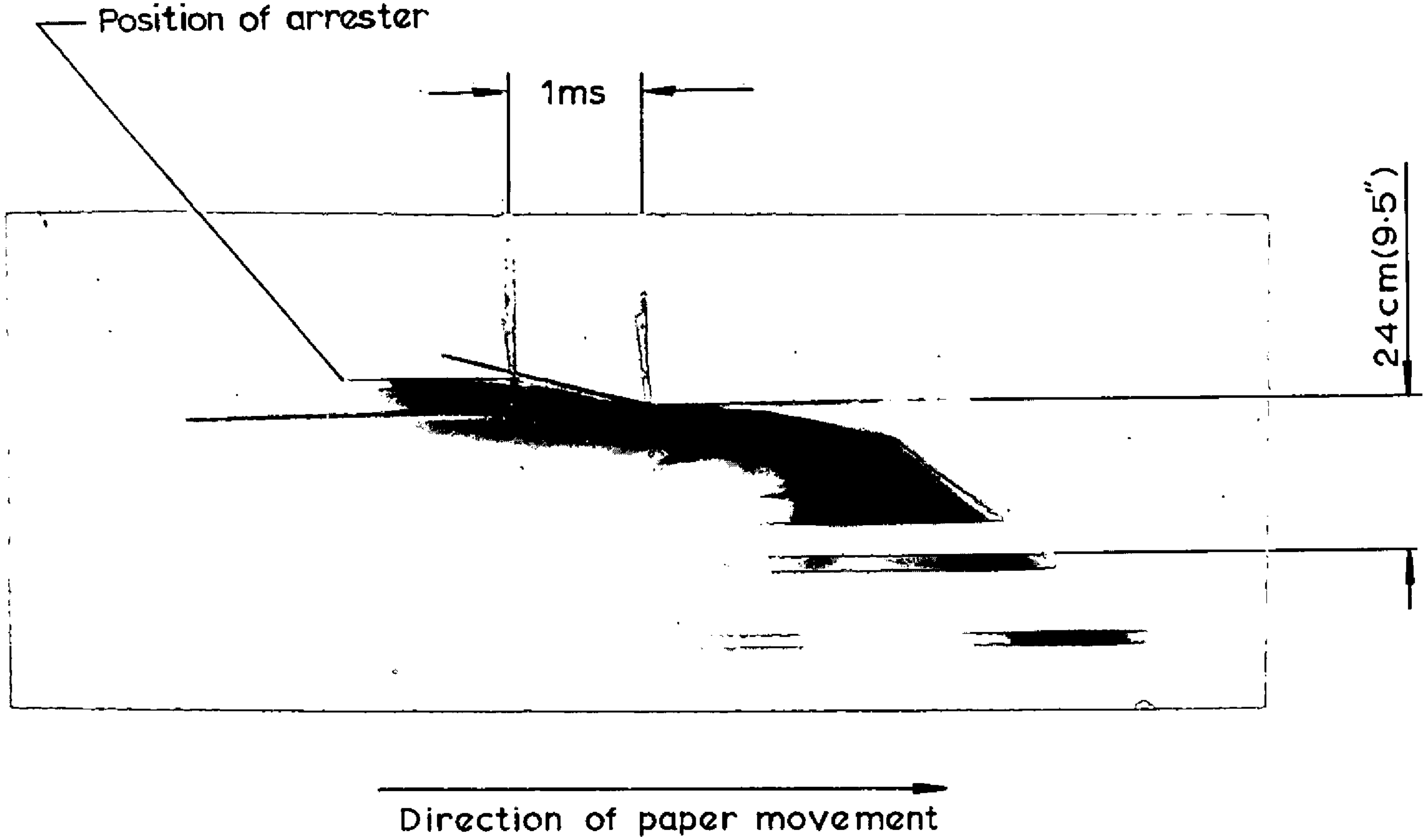


FIG.4 FLAME SPEEDS RECORDED WITH VARIOUS ARRESTERS



Arrester 10 nominal pores
Flammable gas 6·5 per cent ethylene-air

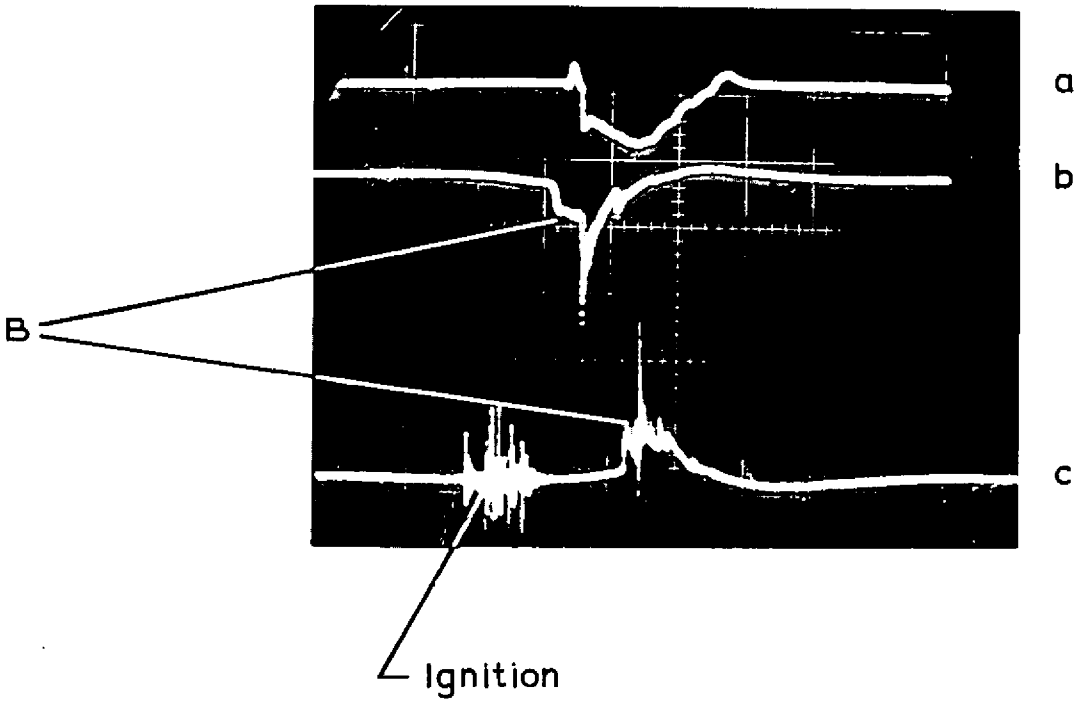
FIG.5 DRUM CAMERA RECORD



Arrester 45 nominal pores

Flammable gas 6·5 per cent ethylene-air

FIG.6 DRUM CAMERA RECORD

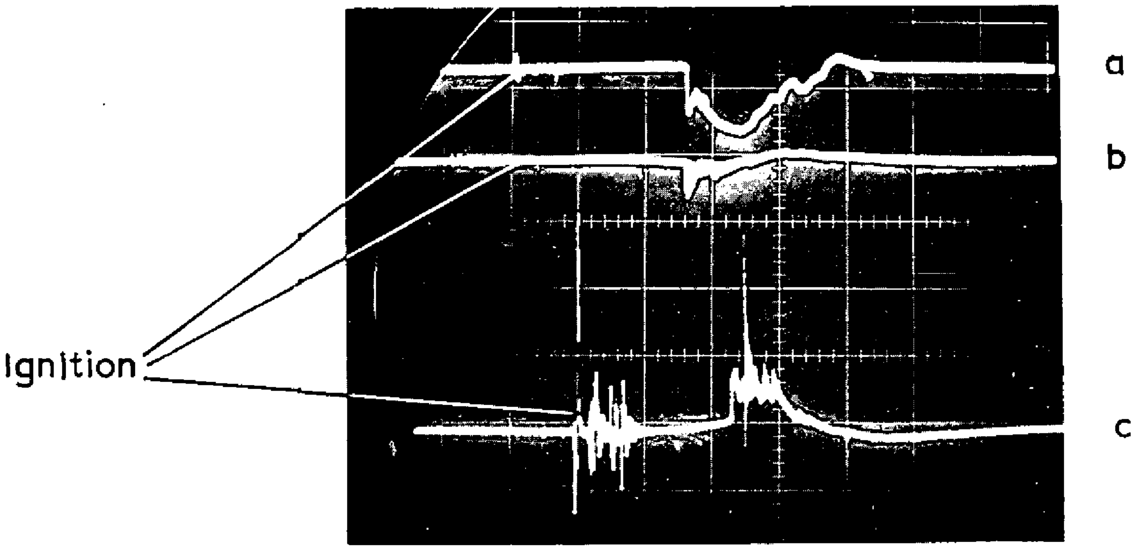


Time base 5 ms/major division
Pressure 350 kN/m^2 (50 lbf/in^2)/major division

NB Trace c displaced 1 major division to the right

Arrester 45 nominal pores
Flammable gas 6·5 per cent ethylene–air

FIG. 7 PRESSURE RECORD

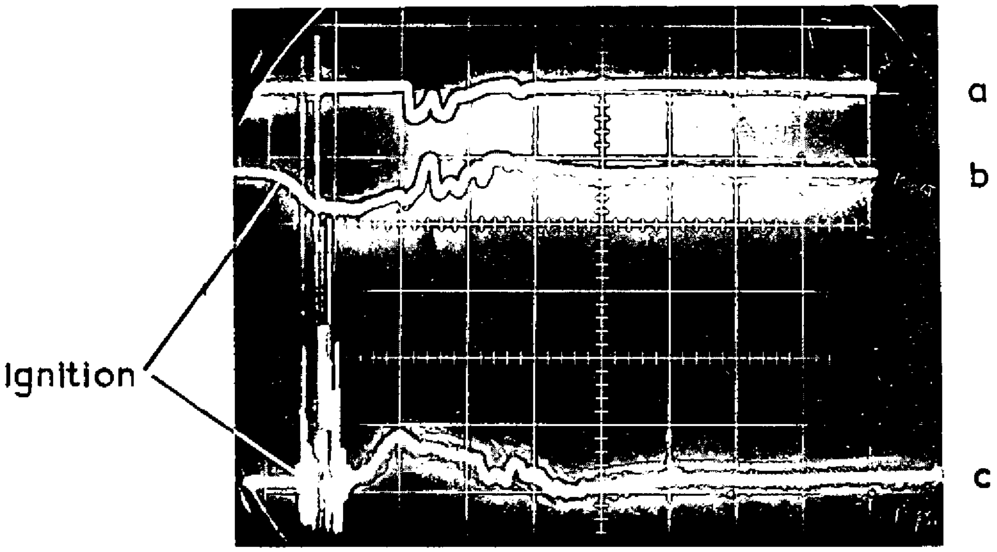


Time base 5 ms/major division
Pressure 350 kN/m^2 (50 lbf/in^2)/major division

NB Trace c displaced 1 major division to the right

Arrester 45 nominal pores
Flammable gas 6·5 per cent ethylene – air

FIG. 8 PRESSURE RECORD



Time base 10ms / major division

Pressure 70 kN/m^2 (10 lbf/ in^2)/major division

NB Trace c displaced 1 major division to the right

Arrester 45 nominal pores

Flammable gas 6·5 per cent ethylene–air

FIG. 9 PRESSURE RECORD

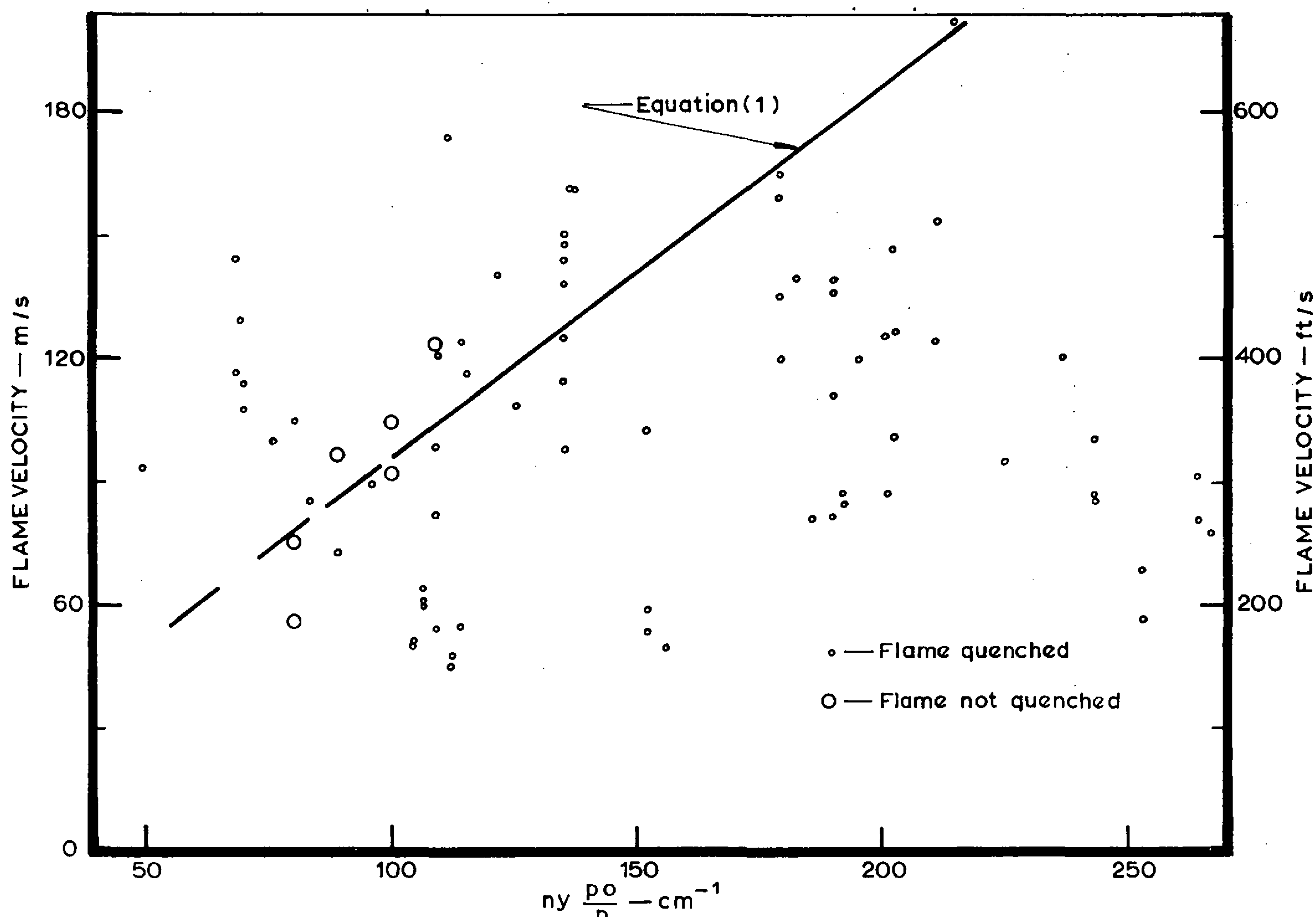


FIG.10 THE QUENCHING OF FLAMES WITH ALLOWANCES FOR EXPLOSION PRESSURE