F.R. Note No. 257/1956
Research Programme
Objective

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THE VENTING OF GAS AND VAPOUR EXPLOSIONS IN DUCT SYSTEMS

Part 1

EXPLOSIONS OF PENTANE VAPOUR-AIR MIXTURES IN A CLOSED TUBE 6FT LONG X 6IN. DIAMETER

by

D. J. Rasbash and Z. W. Rogowski

Summary

A series of measurements has been made of the pressure developed in explosions of pentane-air mixtures in a closed tube 6 ft long x 6 in. diameter. A maximum pressure of 94 p.s.i. was found to occur in mixtures containing 3.4 - 4.0 per cent of pentane. The initial stages of the pressure time-record were more reproducible when a spark was used as an ignition source, than when a proprietary safety fuse was used.

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Fire Research Station,
Boreham Wood,
Herts.

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Introduction

An important safely problem in industry is the mitigation of the effects of gas and vapour explosions which might occur in industrial plant. One of the ways in which this is accomplished is by the provision of relief vents. A programme of work has been started at the Joint Fire Research Organization, the object of which is to provide data which will allow sizes of these vents to be specified. In order to study the relative efficiency of various types of vents it is necessary to employ a standard explosion which gives a reproducible rate of pressure rise up to the pressure at which the vents operate. This report gives an account of a study of pentane-air explosions in a straight closed tube 6 ft long x 6 in. diameter. The object of this work was partly to study phenomena occurring during pentane-air explosions under these conditions but mainly to lay down conditions for a standard explosion in the tube to be used in comparing the efficiencies of vents of various types.

Experimental

Apparatus

Explosion tube. This was a pipe 6ft long x 6 in. internal diameter, flanged at both ends (see Figure 1). Both ends could be blocked with blank flanges. Three 1 in. B.S.P.T. mixing outlets A, B and C were welded on the pipe at right angles, at 6 in., 3 ft and 5 ft 6 in. from one end of the pipe. Provision was made for screwing on a pressure measuring gauge at D or in the centre of the flanges. The source of ignition could be inserted at E through a $\frac{5}{8}$ in. B.S.F. fitting. The same fitting was used for the introduction of the flammable liquid. The flammable gas and air were mixed by a 6 in. diameter centrifugal blower F.

Pressure recording apparatus. A quartz piezo-electric gauge, and associated equipment for recording dynamic pressures, as described by Margerson and Robinson (1) and Titman (2) was used. This essentially consisted of a quartz gauge, an impedance converter, a double beam oscilloscope and a signal generator to give the timing wave on the record. Figure 1 shows diagrammatically the layout of the apparatus. The single sweep on the cathode ray tube was recorded by a camera.

Ignition methods. In all the tests the ignition source was at the axis of the tube. For the majority of the experiments, proprietary electric safety fuses were used. These consisted of a resistance wire 0·5 to 1·5 ohms, embedded in a flammable substance. When sufficient current was passed through the wire, this fused and initiated the combustion of the flammable solid, which burned explosively. The ignition system and the cathode ray tube sweep initiating circuits are shown in Figure 2a. Both circuits were operated from the double pole switch C. On depressing the switch, the circuit governed by the right hand pole of the switch started the single sweep of the beam on the cathode ray tube instantaneously. The left hand pole of the switch C operated the ignition circuit. On closing the switch, relay F closed the contacts B and the fusion of the resistance filament A in the fuse took place. On fusing the filament the secondary winding of the induction coil E sparked on the electrodes H and this marked the instant of ignition on the cathode ray tube. To reduce the radiation pick-up from the spark to an acceptable level a suitable resistance G was inserted in series with the spark gap. The object of the relay F was to delay the ignition for a suitable period, so that it could be recorded at a suitable point on the cathode ray tube screen. Some tests were also done, mainly with a mixture containing 3·37 per cent pentane, in which the mixture was ignited by an inductive spark delivered from a car induction coil; this ignition source proved to be reliable only within a narrow range near the stoichiometric composition. When the inductive spark was used the firing circuit was modified as shown in Figure 2b. On depressing the switch C contacts B of the relay F interrupted a current in the primary winding of the coil E and then the spark would occur in the spark gap A. The width of the spark gap was 1 mm.

Test procedure

In all experiments a measured quantity of liquid pentane (boiling range 32 - 40°C) was introduced into the tube at E (see Figure 1), while allowing the pressure to remain constant by letting air leave the apparatus through the open valves A and D. Valve D was then closed, valves B and C opened and mixing allowed to take place for six minutes. Valves B and C were closed and the mixture ignited.

The liquid was introduced as vapour since the direct introduction of the liquid into the tube gave rise to errors since some of the liquid lodged in crevices between the flanges. The pentane was vaporised by placing it in a glass bulb and surrounding the bulb with hot water. A glass tube heated to prevent condensation connected the bulb and the explosion tube and the residual volume of vapour in the bulb was expelled with hot water.

Tests for leaks and efficiency of mixing

The presence of leaks within the system and the efficiency of mixing were tested by using carbon dioxide within the system rather than pentane vapour, since an infra-red analyser for carbon dioxide was available. 0·04 cu. ft of carbon dioxide was metered into the tube at the same point at which the pentane was introduced. Continuous sampling during mixing showed that complete mixing took place in 1½ minutes; after 6 minutes of stirring the carbon dioxide content had dropped by 1½ per cent. A separate test also showed that during the introduction of a volume of carbon dioxide (7) equivalent to the largest volume of pentane introduced during the experiments, no leakage of carbon dioxide took place through the air leak valve kept open during the filling process.

Results

Pressure records

Typical examples of pressure records, obtained with 3·37 per cent pentane, for fuse ignition and spark ignition are shown in Figure 3(a) and (b) respectively. In most of the tests vibrations of a main frequency of 250 c/s were recorded. These vibrations began at a time prior to the peak pressure being reached and developed a maximum amplitude at the peak pressure. When fuse ignition was used the shape of the pressure records obtained, even for a given mixture was very variable. There was generally a delay of between 0·02 and 0·07 sec., from ignition to the commencement of the pressure rise followed by a rapid rise up to about 30 p.s.i. After this, the rate of pressure rise dropped for a time but rose again shortly before the maximum pressure was recorded. A few tests in which fuse ignition was used gave records without vibrations: an example of such a record is shown in Figure 4. In these tests the rate of pressure rise was much slower and the maximum pressure was less than in tests using the same percentage of pentane in which vibratory records occurred. In nine tests carried out with a 3·37 per cent pentane mixture in which an inductive spark was used as the ignition source, the pressure records obtained were much more reproducible than those obtained in tests carried out with the same mixture using fuse as an ignition source. This point is illustrated in Figure 5: (a) shows the outline of five tests with fuse ignition: (b) of seven tests with spark ignition. With fuse ignition variations occurred throughout the whole of the pressure record. With spark ignition the reproducibility of the pressure record was good up to a pressure of about 30 - 40 p.s.i. A certain amount of variation occurred at high pressures where the records were characterised by vibrations. When the ignition was by inductive spark a variation of mixture strength between 2·8 per cent and 3·8 per cent, produced only small variations in the initial rate of pressure rise; nevertheless the initial rate of pressure rise was the greatest for a 3·37 per cent mixture. This is shown in Figure 6.

Maximum pressure and mean rate of pressure rise

Table 1 gives a summary of the tests carried out with the fuse ignition source, and contains P_m, the maximum pressure reached, measured at the centre of the vibrations, R_1 the mean rate of rise of pressure between the commencement of the pressure rise and the maximum, and R_2, the mean rate of rise of pressure between the commencement and the sharp inflection that usually occurred at a pressure of 30 p.s.i. In Figure 7 the maximum pressure P_m is plotted against the composition. Figure 7 shows non-vibratory explosions marked separately and they are not included in the mean. Figure 7 shows that the greatest maximum pressure of 94 p.s.i. occurs between 3·4 and 4·0 per cent pentane concentration. The scatter of results does not justify any closer limits to be drawn. Figure 8 shows the mean rates of pressure rise plotted against the concentration of pentane. Here the scatter of results is even greater; however the maximum rate of pressure rise occurs again between 3·4 and 4·0 per cent of pentane concentration.

Table 1a shows peak pressures and average rates of pressure rise for those tests with the 3·37 per cent pentane mixture when ignition was by an inductive spark. Although the maximum pressures are lower than those obtained with ignition by the fuse, the mean rate of pressure rise was reasonably reproducible.

Discussion

Little work has been done on explosion pressures of pentane air mixtures in tubes. Wilson (3) used a cylindrical vessel of 60·5 cu. ft capacity 4 ft 2 in. in diameter and his results are summarized in Table 2. Maximum pressures in his work were higher and the greatest pressure occurred at a pentane concentration of 3·25 per cent. This concentration is somewhat less than that found in the present work. The higher pressures obtained by Wilson may be accounted for by the relatively smaller amount of cooling surface present. Wilson quotes certain maximum rates of pressure rise for different concentrations (see Table 2); in this work large variations occurred in the rate of pressure rise particularly while using fuse ignition and therefore only average rates of pressure rise could be reasonably calculated.

Effect of ignition source on reproducibility

The variability of the results caused by fuse ignition may be accounted for by the turbulence created on setting off the fuse. Increases in the rate of pressure rise caused by turbulence have been reported by Wilson and Preston, Roberts and Thomas (5) Shelkin (4). Again it is likely that the fuse started ignition at several points simultaneously and the number of these points varied from test to test. However ignition by the inductive spark seems to have eliminated the major variations which were encountered. Here it is likely that the initial rapid rate of pressure rise occurred before the flame met the walls of the pipe which would cool the flame. This initial portion of the time-pressure curve was, for a given mixture identical in all tests and was characterised by the absence of any vibrations.

Standard explosion

The above results show that an explosion which is reproducible up to a pressure of 30 - 40 p.s.i. can be obtained if an inductive spark is used as the ignition source. The results also show that although the most violent explosion, measured by the maximum pressure developed and the rate of pressure rise, is likely to occur with the 3·4 per cent mixture, that there is little difference in the rate of pressure rise up to about 20 p.s.i. with variations between 2·8 - 3·8 per cent, if an inductive spark is used. Since vents are expected to operate at low pressures, reproducibility in a standard explosion for testing vents is more important in the initial stages than in subsequent stages. It may therefore be concluded that a mixture containing 3·4 per cent pentane will, when ignited by an inductive spark, give sufficiently reproducible explosions to allow the comparison of various types of vents. More violent explosions could be made to occur, however, if a fuse is used as an ignition source but these would suffer from lack of reproducibility.

References

1. S. H. A. Margerson & H. Robinson. A Piezo-Electric Recording Manometer. Safety in Mines Research Establishment. Research Report No. 82. December, 1952.

2. H. Titman. Measurement of dynamic pressures. Safety in Mines Research Establishment. Research Report No. 12. November, 1950.

3. Wilson, M. J. G. Thesis. Imperial College of Science and Technology. London, 1954.

4. Shelkin, K. J. J. Tech. Phys. Moscow, 1947, 17(5) 613-8.

5. H. G. Preston, J. D. Roberts and A. Thomas. Crankcase explosions: An investigation into some factors governing the selection of protective devices. Inst. Mech. Eng. 1946.

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TABLE 1

Peak pressures and average rates of pressure rise.
Ignition by fuse

No.	Pentane content (per cent by volume)	Pm The maximum pressure reached (p.s.i.)	R_1 The mean rate of rise of pressure between the commencement of the pressure rise and the maximum (p.s.i./sec.)	R_2 The mean rate of rise of pressure between the commencement and the sharp inflection (p.s.i./sec.)	Comments
1	2.27	71	n.d.	n.d.	
2	" "	71	222	337	
3	" "	60	125	162	No vibrations
4	" "	61	116	263	No vibrations
5	2·53	80	320	346	
6	" "	78	n.d.	n.d.	
7	" "	67	172	390	No vibrations
8	2·82	93	465	428	
9	" "	81	358	554	
10	" "	92	410	338	
11	3·05	90	403	465	
12	" "	91	478	561	
13	" "	90	547	804	
14	" "	68	314	427	No vibrations
15	3·37	94	493	486	
16	" "	95	475	396	
17	" "	92	687	773	
18	" "	93	424	389	
19	" "	88	587	482	
20	3·79	96	598	1350	
21	" "	86	356	557	
22	" "	88	510	566	
23	3·95	96	389	408	
24	" "	94	526	742	
25	4·14	90	558	586	
26	" "	95	392	240	
27	4·50	76	224	222	
28	" "	80	250	273	
29	" "	75	182	388	

TABLE 1a

Peak pressures and average rates of pressure rise.
Ignition by inductive spark

No.	Pm The maximum pressure reached (p.s.i.)	R_1 The mean rate of rise of pressure between the commencement of the pressure rise and the maximum (p.s.i./sec.)
1	86	358
2	80	345
3	81	306
4	84	336
5	96	480
6	87	342
7	86	358
8	84	336
9	81	415

TABLE 2

Explosions of pentane-air mixtures in closed vessel
(after Wilson)

Mixture pentane per cent	Maximum pressure (p.s.i.)	Maximum rate of pressure rise (p.s.i./sec.)
2·0	93	390
2·3	108	750
2·7	113	900
3·0	117	1,700
3·25	122	3,300
3·5	110	3,700
4·0	106	3,200
4·3	109	2,800

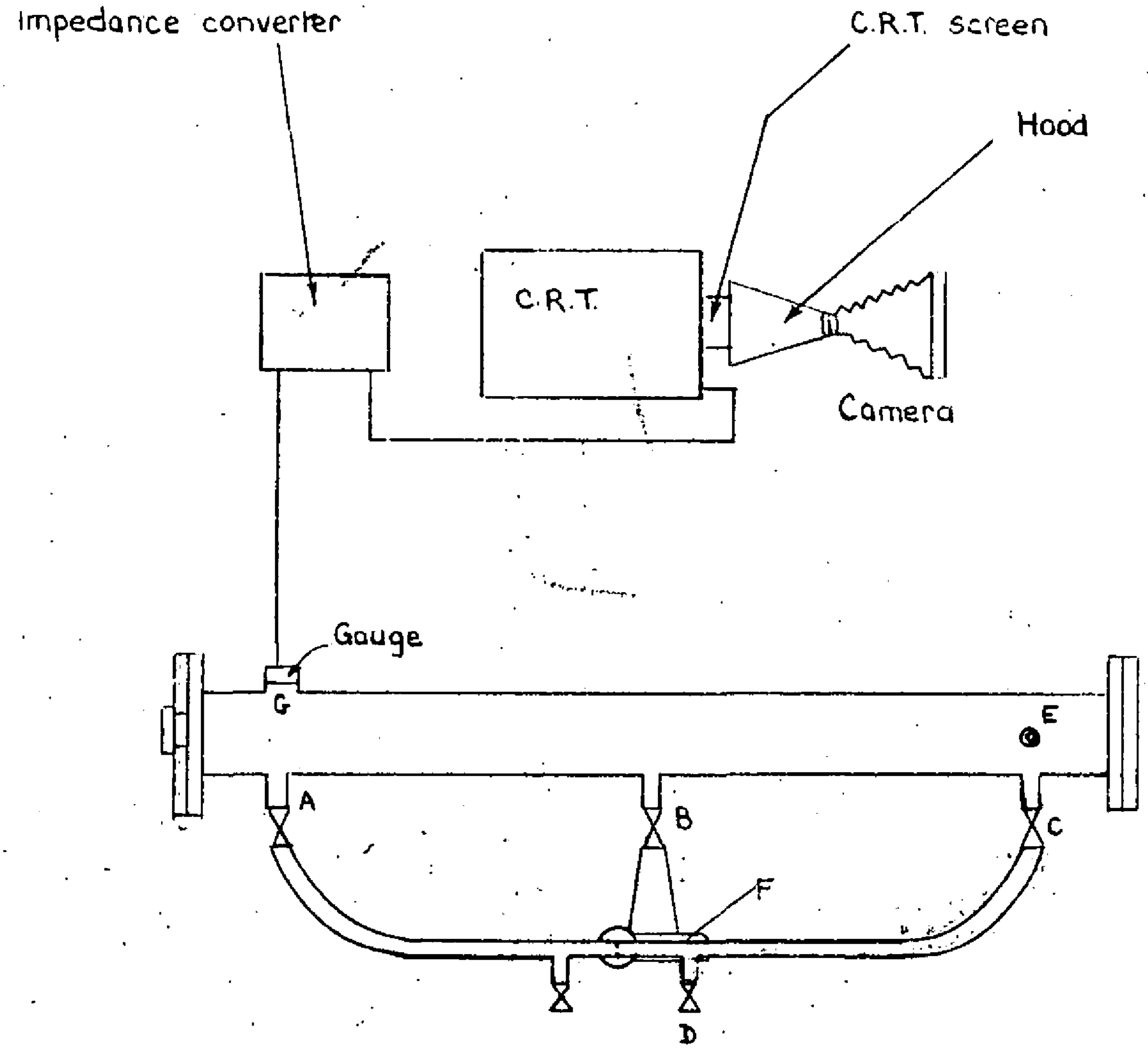
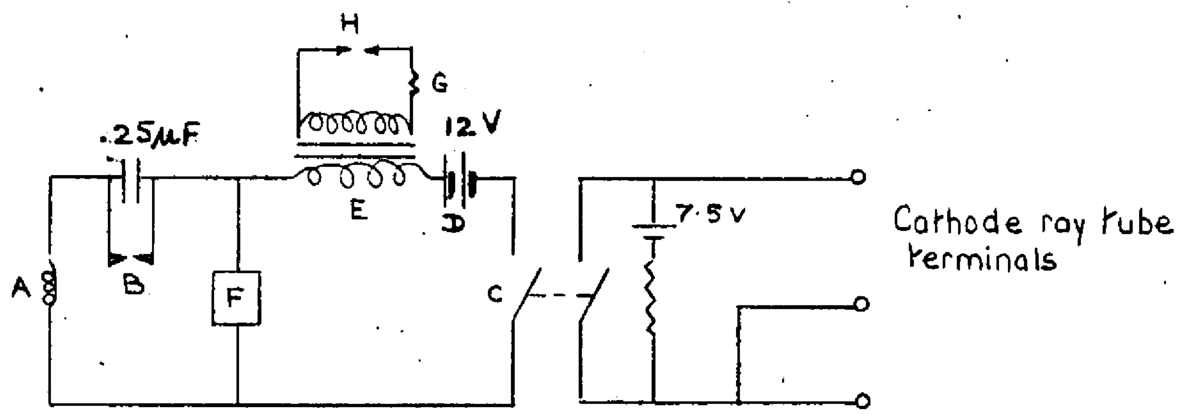
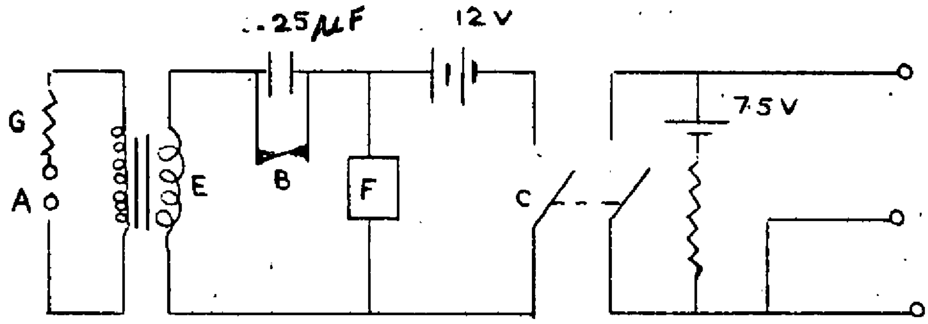


FIG. I. LAYOUT OF APPARATUS

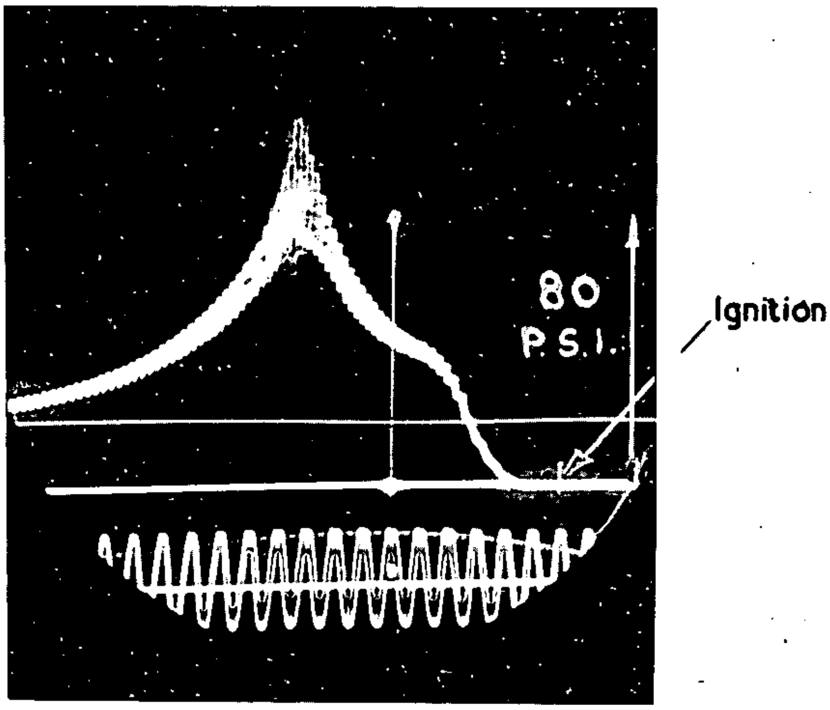


(a) FUSE-IGNITION



(b) INDUCTIVE SPARK IGNITION

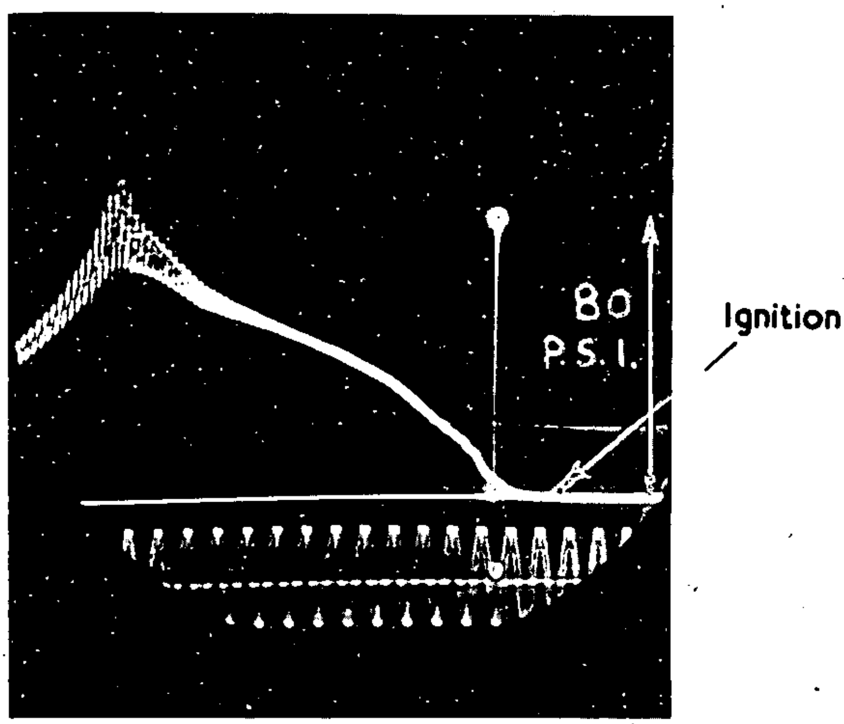
FIG. 2. CIRCUITS FOR IGNITION SYSTEMS



← TIME 50 c/s

(a) FUSE IGNITION

3·37 PER CENT PENTANE IN AIR

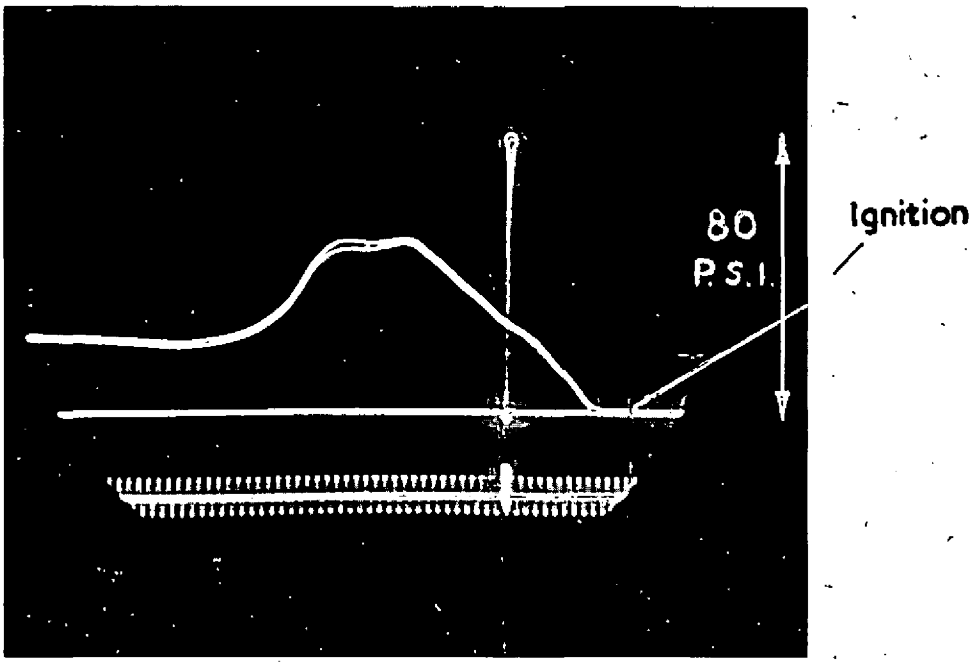


← TIME 50 c/s

(b) INDUCTIVE SPARK IGNITION

3·37 PER CENT PENTANE IN AIR

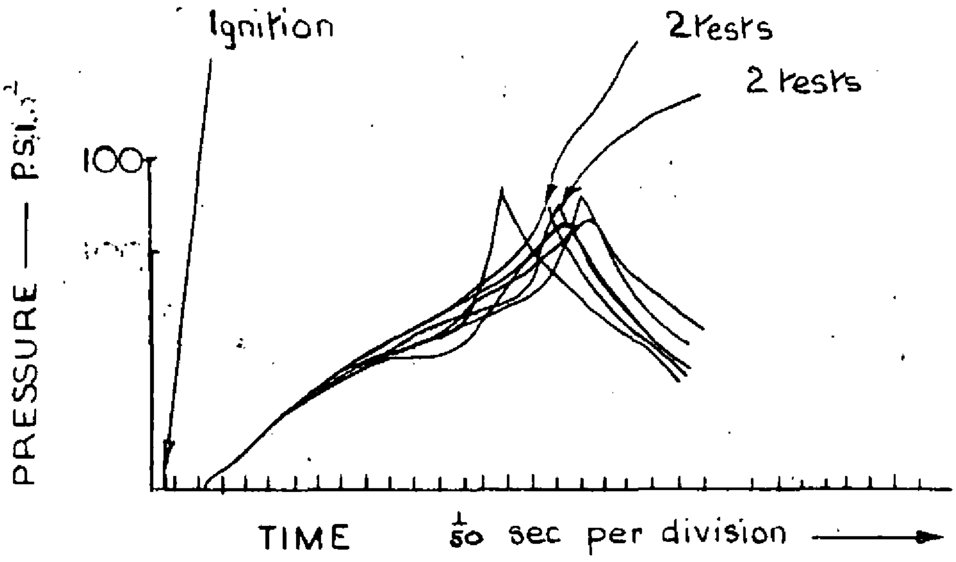
FIG. 3. TYPICAL PRESSURE RECORDS



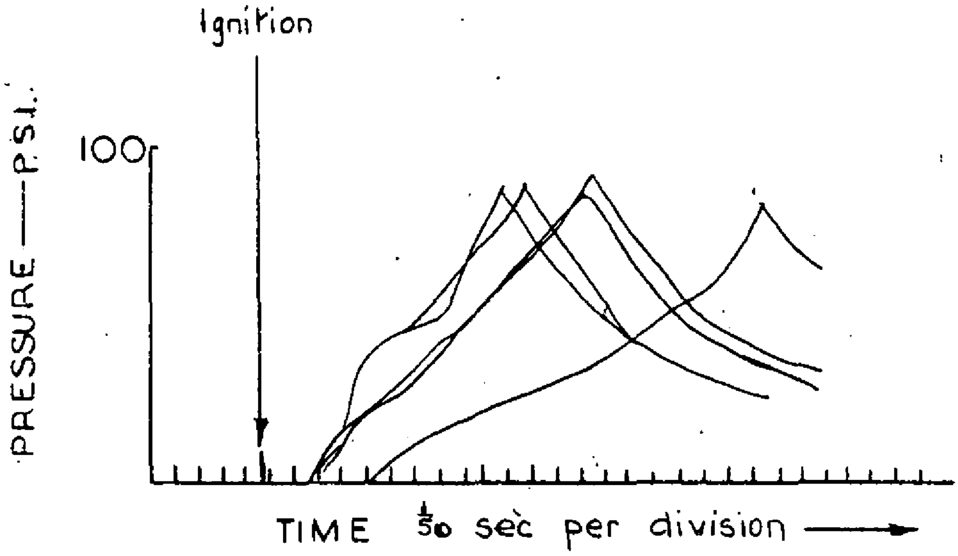
TIME 50 c/s

2·27 PER CENT PENTANE IN AIR

FIG. 4. NON-VIBRATORY PRESSURE RECORD



(b) INDUCTIVE SPARK IGNITION



(a) FUSE IGNITION

FIG 5 REPRODUCIBILITY OF PRESSURE-TIME RECORDS

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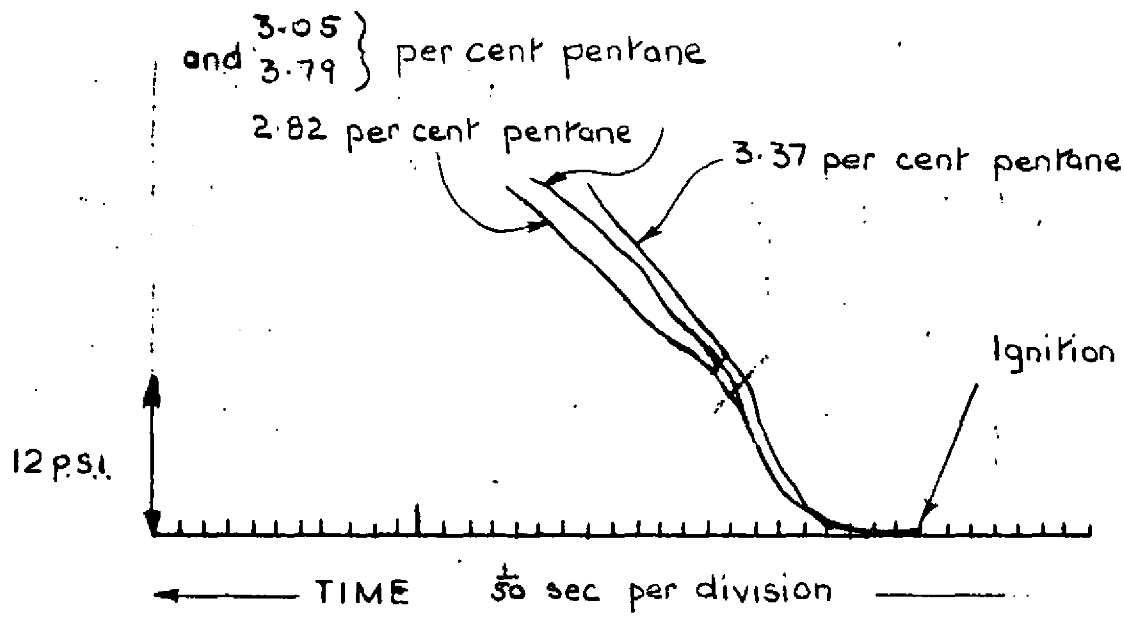

FIG. 6. EFFECT OF MIXTURE COMPOSITION ON THE INITIAL RATE OF PRESSURE RISE.
IGNITION BY INDUCTION SPARK

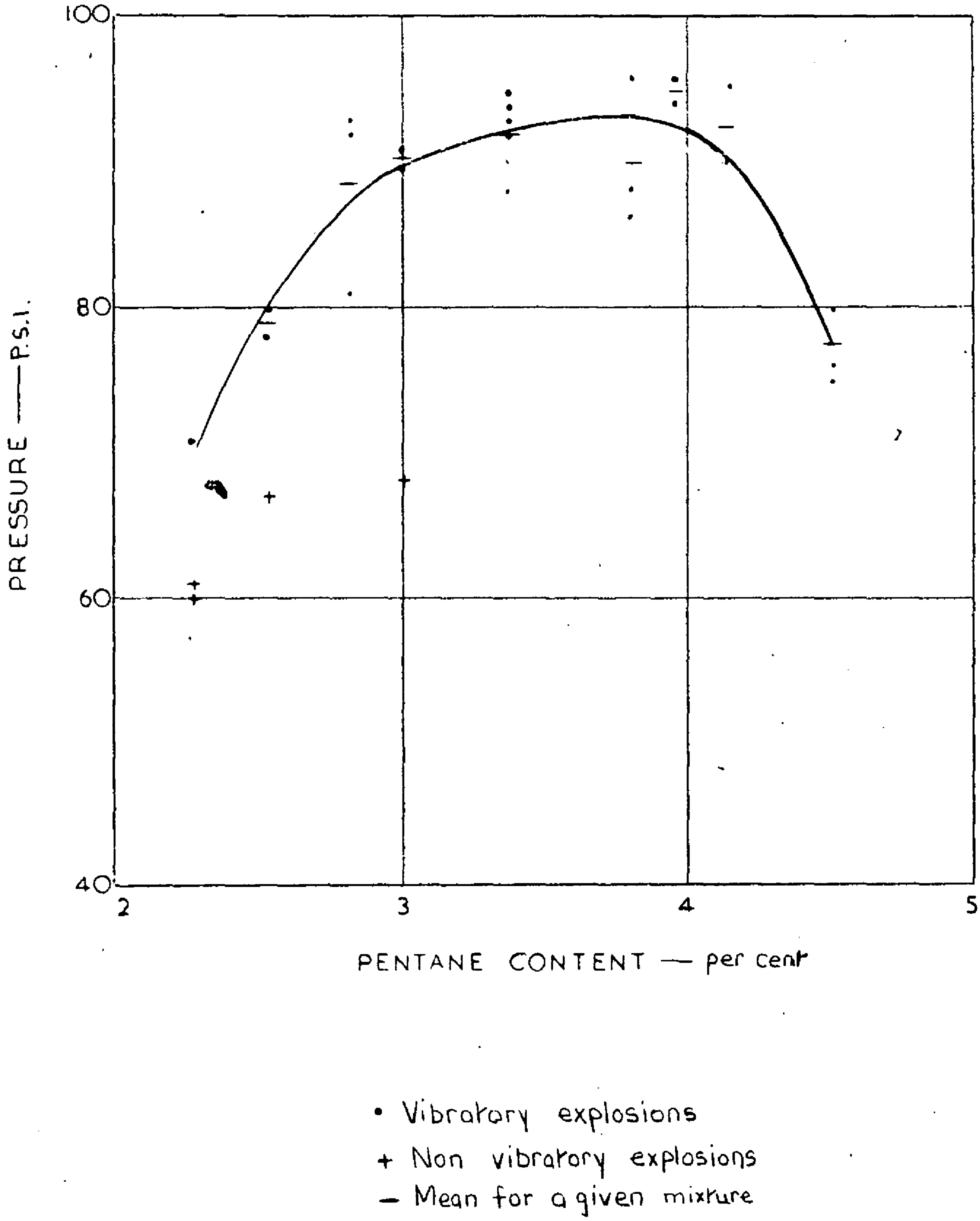

FIG. 7. THE EFFECT OF MIXTURE COMPOSITION ON THE MAXIMUM PRESSURE (IGNITION BY FUSE)

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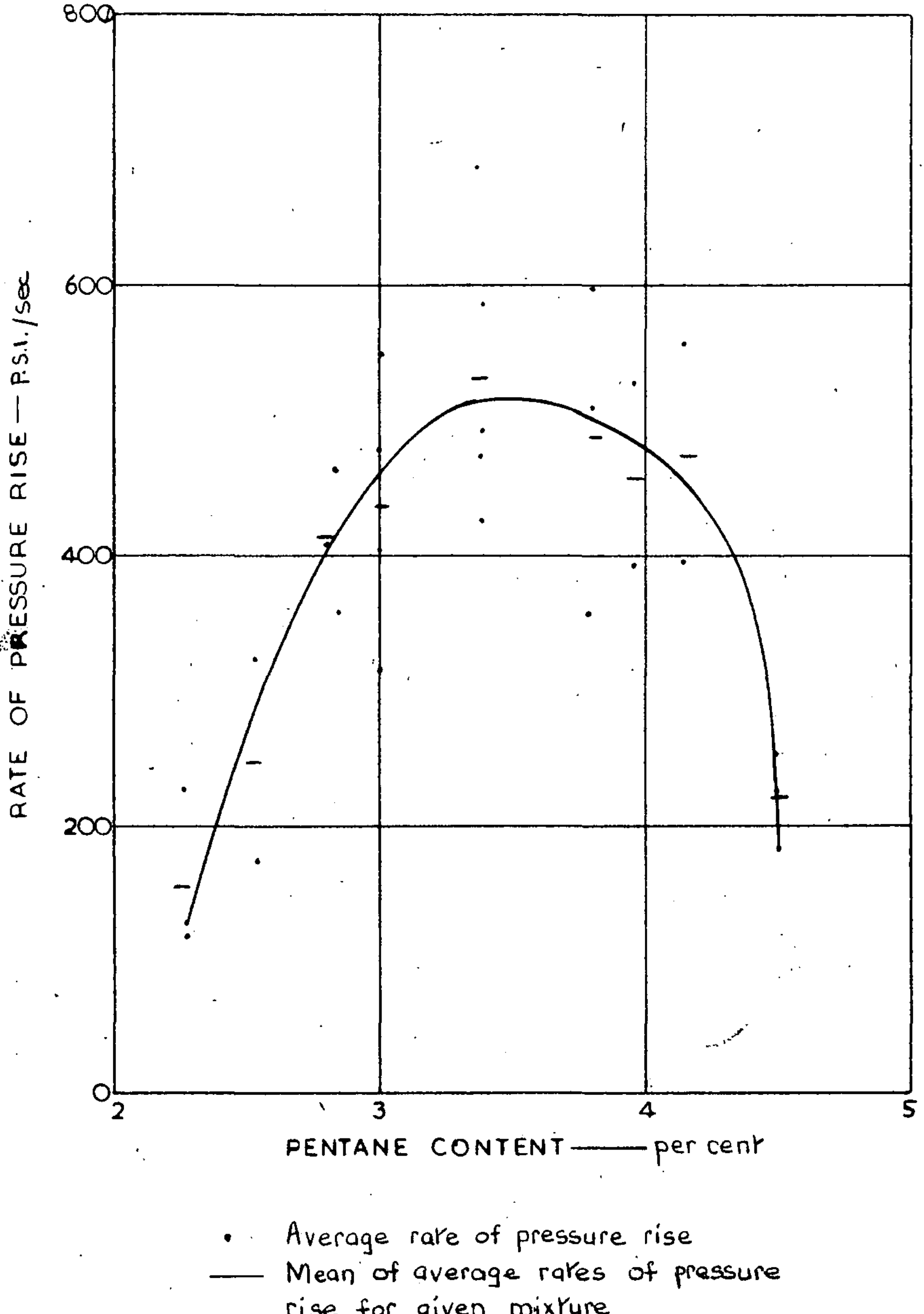

FIG. 8. EFFECT OF MIXTURE COMPOSITION ON THE AVERAGE RATE OF PRESSURE RISE BETWEEN COMMENCEMENT OF THE PRESSURE RISE AND THE MAXIMUM. (IGNITION BY FUSE)

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