Fire Research Note No 1019

PRESSURES PRODUCED BY GAS EXPLOSIONS IN A VENTED COMPARTMENT

by

R N Butlin and P S Tonkin

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FIRE
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SUMMARY

Measurements have been made of the pressures and sound levels generated over a range of distances from a single compartment in which layers of nominally stoichiometric mixtures of natural gas and air, (10 per cent natural gas) were ignited and vented through vents of different depths.

Relationships are presented for the variation of maximum explosion pressure within the compartment and the depth of the layer of explosible mixture for each vent depth, and for the variation of maximum pressure and sound levels with distance from the compartment in which the explosion occurred.

For explosions in a compartment vented on one side only, the maximum external pressures recorded at sites normal to the vent opening vary inversely with distance from the compartment. Sound levels are reduced by 6 dB on doubling the distance from the explosion compartment.

Department of the Environment and Fire Offices' Committee
Joint Fire Research Organization

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INTRODUCTION

The Fire Research Station commenced a programme as part of a larger research programme initiated after the gas explosion at Ronan Point. Descriptions of the basic experimental facilities and measuring techniques are either published or are in the process of being published. This note presents the first sets of experimental data on explosion pressures and sound levels obtained in this programme together with preliminary assessments. A fully detailed analysis of these results will not be made here, as this will be considered at a later date, when more experiments have been completed.

The results presented in this report are for explosions of layers of a stoichiometric natural gas-air mixture at ceiling level in a 28 m^3 explosion chamber. Pressure relief was afforded by openings of different areas on one side of the explosion chamber, using a thin polyethylene sheet as a vent cover.

APPARATUS

The details of the 28 m^3 chamber used in these experiments[1], the methods of producing and introducing gas mixtures into the cell in the form of ceiling layers, their subsequent analysis for gas distribution, the methods of measuring the pressures developed inside and outside the chamber[2] and the methods of measuring sound levels will be reported fully elsewhere. Figure 1 is a photograph of the explosion chamber.

The criteria for layer formation and the associated research into the formation of layers of explosible gas mixtures in the chamber will be reported in two separate notes. In the present series of tests, the effect of varying the layer depth and the vent area on the pressures developed inside and outside the cell have been investigated.

The vent areas used were $\frac{1}{2}$, $\frac{1}{4}$ and $\frac{1}{8}$ of the total area of the front face of the chamber, 7.2 m^2. The vent areas were obtained by fitting standard Braithwaite tank sections to the face of the cell in such a way as to leave a vent in the form of a rectangular aperture of the full width of the chamber, 3 m, bounded by the roof of the chamber and the upper edge of the inserted Braithwaite panels, to give vent depths of either 1.20 m, 0.6 m or 0.3 m, (areas of 3.6, 1.8 and 0.9 m^2). In order to maintain an approximately constant bursting pressure of vent material for the tests with different vent areas, polyethylene sheet 0.05 mm thick was clamped peripherally over the whole of the front face of the chamber for each vent size. Natural gas/air mixtures were introduced into the chamber until a layer of depth n (in metres) had been produced. The criterion for a layer of depth n was that the gas mixture was introduced until rapid analysis[3] showed a minimum of 95 per cent of the input gas concentration at depth n. The filling of the chamber was then discontinued. Ignition in all cases was by a single high voltage spark source at a depth n at the rear of the chamber. The firing of the ignition device triggered all the recording instruments (mainly oscilloscopes) and the variations of the different parameters with time were recorded photographically. The variables measured in these experiments were: internal pressure, external pressure and sound levels at different distances away from the chamber. A limited number of high-speed cine recordings have been made.

RESULTS

Internal pressure measurements

Details of the shape of the pressures-versus-time profile changes and classification of the different forms over the range of pressures recorded with different vent areas and layer depths will not be given in this note. The shape of the internal pressure (measured at the chamber wall) versus time profile for a vented explosion of moderate relative intensity is, however, indicated in Fig. 2. The profile is for a 1.83 m layer of 10 per cent natural gas in air, with a 3 m x 0.6 m vent at the top of the front of the chamber constituting a vent of 0.25 times the maximum available vent area, ignited at the 1.83 m level by a single spark source. It will be seen that 320 ms after ignition a small pressure peak appears on the trace with a maximum pressure of about 0.7 kN/m^2. This represents the pressure at which the vent material (polyethylene) bursts and this pressure was maintained consistently for all the experiments in the series. 540 ms after ignition another pressure peak appears of value 2.1 kN/m^2 followed closely at 600 ms by a very sharp pressure peak of value 8.3 kN/m^2. This double pressure peak phenomenon is well established in gas explosion venting work and has been explained qualitatively by Cubbage and Simmonds[4]. It does not occur in every instance, but tends to occur with small vents.

A systematic study of the maximum internal pressure generated (for the series of three vent areas mentioned earlier) by explosions in different layer depths of 10 per cent natural gas/air mixtures is presented in Fig. 3. The pressures recorded are the mean maxima for triplicate experiments in each case. It will be seen from Fig. 3 that for each vent area the maximum pressure generated increases smoothly with layer depth in an approximately parabolic form. The empirical equation of 'best fit' based on a parabolic regression of the experimental data are given for each curve in Fig. 3. As yet there is no theoretical justification for an empirical formula which is parabolic for the effect of layer depth on maximum explosion pressure generated, but the expected form of the relationships will be considered elsewhere. The plots in Fig. 3 do not in general conform to the empirical relationship proposed by Rasbash[5] for vented gas explosions which is of the form

$$P_{max} = AP_V + BK \qquad \ldots\ldots (1)$$

when Pmax is the maximum pressure generated, P_V is the bursting pressure of the vent material, K is the ratio of smallest cross-sectional area of the compartment to the available vent area, and A and B are constants of value 1.5 and 3.5 respectively for pressure units of kN/m^2. Extrapolation of the three curves to layer depth 2.44 m (i.e. with the chamber full of gas) gives theoretical values of maximum pressure of 15, 10 and 7 kN/m^2 respectively for K = 8, 4 and 2, compared with 29, 15 and 8 kN/m^2 from the relation proposed by Rasbash.

<u>External pressure measurements</u>

It was decided at an early stage in the experimental programme that, because of the possible disruptive effects of explosions on neighbouring structures, pressures outside the chamber should be measured. Initially, measurements were taken at distances of 9.14 m (30 ft) and 18.3 m (60 ft) on the centre line normal to the vented side of the cell. A limited number of measurements have been taken adjacent to the cell sidewall and more recently more extensive and accurate distributions of external pressure normal to the vent have been measured, taking measurements at 3 m (10 ft), 6.1 m (20 ft), 9.1 m (30 ft), 18.3 m (60 ft) and 36.6 m (120 ft).

Figure 4 shows the relationship between the maximum pressure at 9.14 m plotted against the external pressure at 18.3 m. The interesting feature of Fig. 4 is that a straight line of slope 0.5 is obtained for all the experiments at the three different vent ratios used in the series. As the relationship is a simple one (doubling the distance halves the pressure) it indicates a simple inverse law

$$p = \frac{k}{d} \qquad \text{..... (2)}$$

where p = external pressure

k = a constant

d = distance from face of chamber

over the range 9.14 m to 18.29 m. This is in accord with the known decay laws for blast waves at a distance from a solid-state explosive device[6]. More detailed distributions of pressure versus distance are given in Fig. 5 for two experiments which include the internal pressure at zero distance.

The simple inverse law is a rectangular hyperbolic relationship and it can be shown that the empirical relationships between external pressure and distance close to the chamber is still hyperbolic but more complex than the simple inverse law, which appears to hold from about 6 m outwards for the present system.

It appears reasonable,therefore, to use the simple law to estimate external pressure at a distance from a gas explosion. In order to estimate the pressure at the origin from the known damage (and hence external pressure at different distances) caused by gaseous explosions, it is necessary either to generalise the form of the equation of the curve close to the point or place of origin, or to generalise about pressures at a specific distance in the simple inverse linear regime with the pressure measured at the origin. This has been done in Fig. 6 of the linear regression obtained for a plot of internal pressure against the external pressure at 9.1 m with data taken for experiments using different vent areas. Thus Fig. 6 indicates a ratio of about 3 for the pressure inside the chamber compared with that at 9.1 m. It must be realised that this kind of estimate of pressure at the origin should not be applied universally and that all the data obtained is for a directionally vented explosion from one size of explosion chamber, so that great care must be exercised in applying this kind of extrapolation generally to completely unconfined explosions.

A useful extension to the simple inverse law would be to account for the directional aspects of pressure decay outside a vented explosion chamber by introducing an extra 'characteristic dimension' into the equation in such a way that the pressures developed near to the chamber would be included. This dimension, in simple terms, might be the effective distance the explosion effects had to travel before being able to decay effectively in three dimensions. The equation would be of the form

$$p = \frac{k}{d + d_o} \quad \text{or} \quad \frac{1}{p} = \frac{1}{k}\,(d + d_o) \qquad \ldots\ldots (3)$$

where d_o is a 'characteristic dimension' of the chamber, k is a proportionality constant, d is the distance from the chamber at which the pressure p is measured. It is not intended in this short note to develop this idea in detail but, as an example, Fig. 7 shows a plot of $\frac{1}{p}$ against d for a single experiment in which the external pressure distribution was determined. The intercept, d_o, on the d-axis is about 3 m. This was the dimension of the cube root of the volume, 3 m, or the depth of the chamber.

A further point that has emerged from this series of experiments is that the pressure acting on the outside surface of the chamber can be of significant magnitude within a very small time interval (20 ms) of that measured inside the chamber. The plan diagram in Fig. 8 shows an example of maximum distribution pressure normal to and at right angles to the cell for a single experiment. It is clear that in connection with the effect of gas explosions in buildings more consideration must be given to the pressure differential on a given wall or element. It is also necessary to consider the external pressure effects on nearby buildings and the possible effects of rarefaction waves.

Sound level measurements

The experimental aspects of sound level measurements will be reported elsewhere. The main points of measuring sound levels were firstly to find the actual sound level instead of relying on estimates from energy equivalence with TNT and scaling the supersonic effects accordingly, and secondly to obtain the laws of decay with distance, in comparison with those for decay of pressure.

Sound levels were measured as peak impulse sound levels with an 'A', weighted network which takes into account factors affecting the response of the human ear. For most experiments, measurements were taken at 18.3 m and 36.6 m. Figure 9 shows a plot of external pressure at 18.3 m versus the measured sound level at the same place. Also shown in the same graph is the theoretical sound level pressure versus decibel plot. Their slopes are identical, i.e. halving the pressure gives a reduction of 6 dB in the sound level, but there is a two order difference in absolute value of pressure.

The reason for this is not understood at present, but it may be related, for example, to the frequency distribution of the explosion pulses compared with that of the weighted network used in the sound level meter, or its response time. In general, in these tests the measured sound level at 9.18 m is 6 dB greater than that at 18.3 m, which provides confirmation of the decay law for external pressure (over a limited range) and of the decay of sound with distance, viz. doubling the distance reduces the sound level by 6 dB. (see Fig. 10)

CONCLUSIONS

Empirical relationships between explosion pressures and layer depth have been obtained for a series of gas explosions involving layers of natural gas/air mixtures of a number of depths in a vented chamber with three vent areas. Approximate laws of decay of pressure and impulse sound level have been established which are of value, for example, in the assessment of the effect of blast waves from explosions in chemical plant, on surrounding property. A more detailed analysis of the data will be made to establish these laws over a wide range of pressures and distances radiating from the source.

ACKNOWLEDGEMENTS

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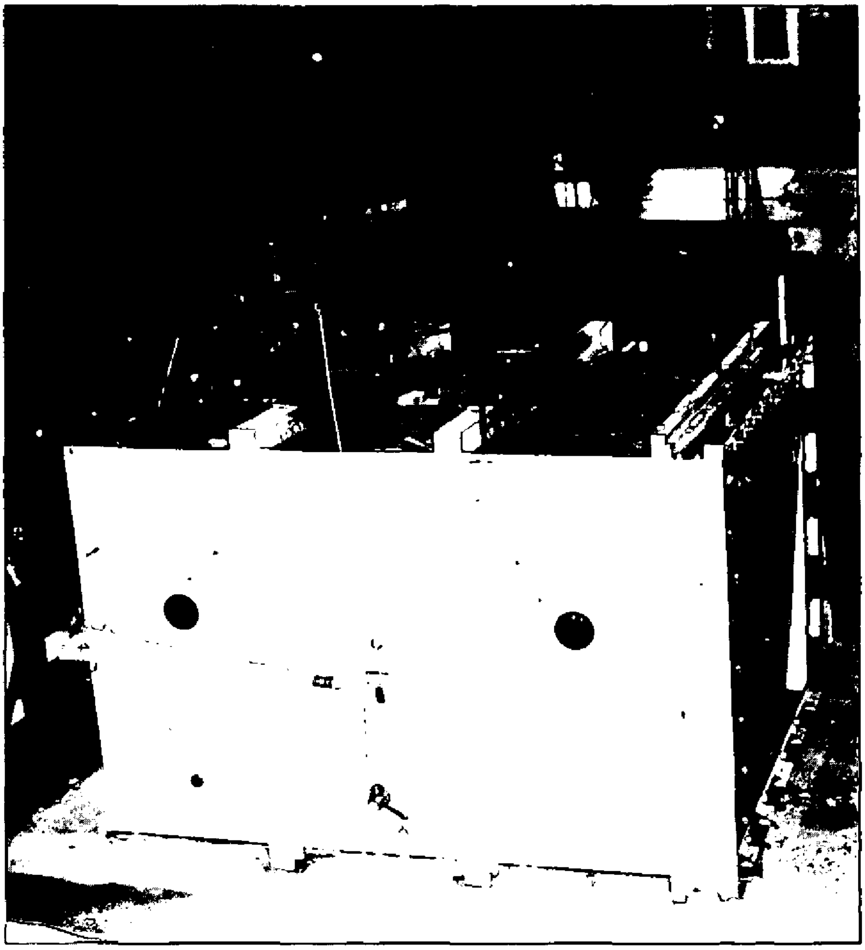

FIG. 1. THE STEEL EXPLOSION CHAMBER
(VENT AT RIGHT HAND SIDE)

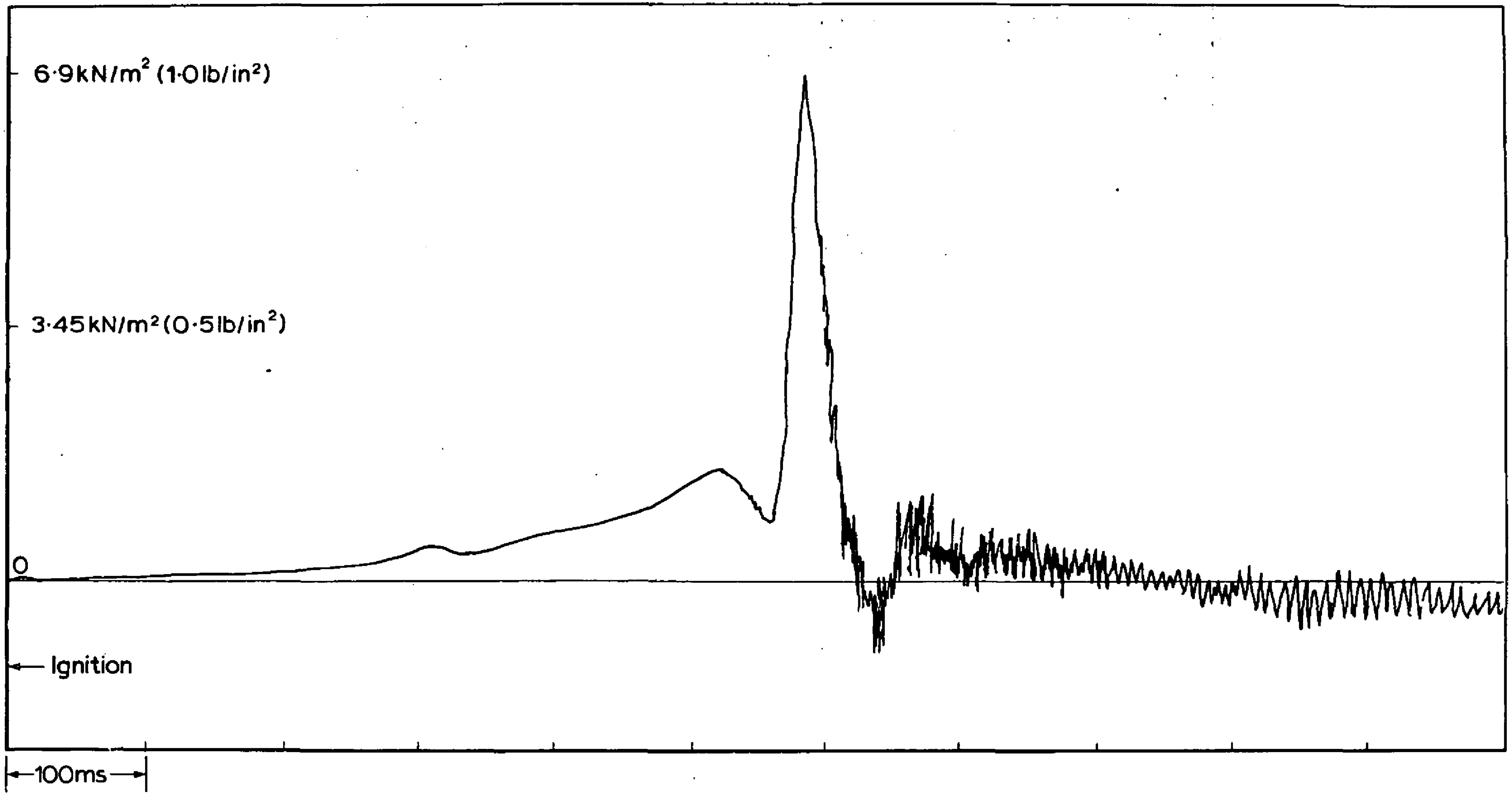

Figure 2 Profile of pressure vs time of vented gas explosion

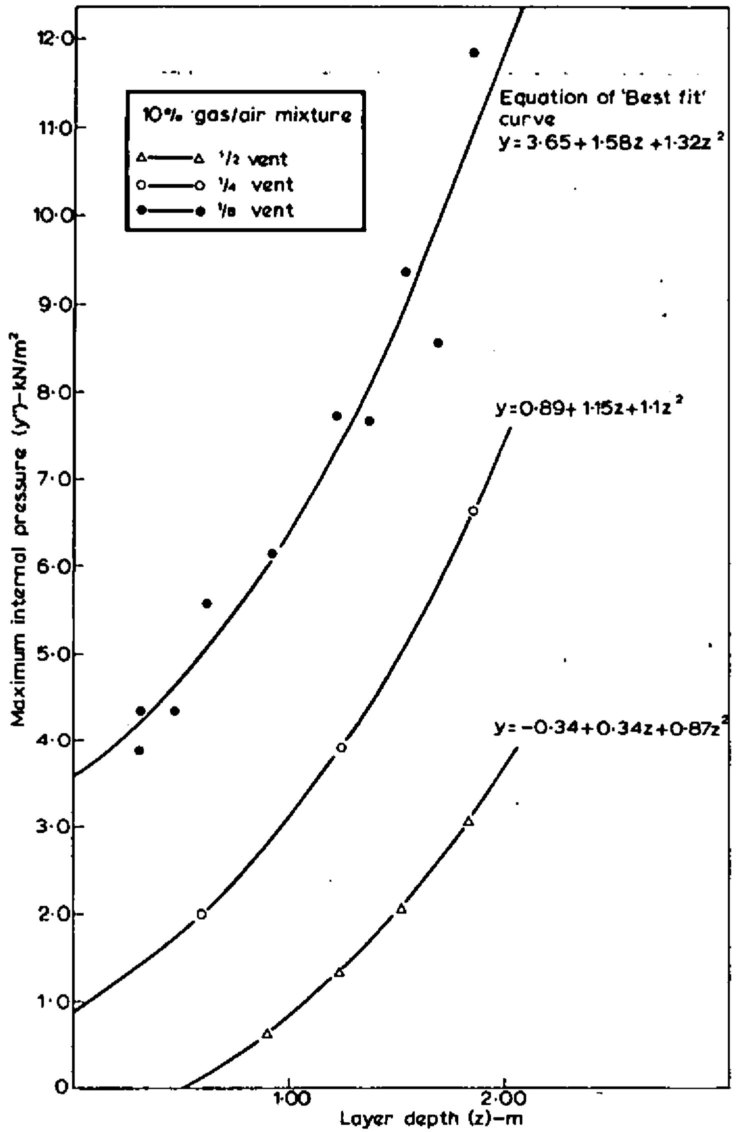

Figure 3 Effect of depth of layer of explosible gas mixture on maximum explosion pressure in chamber

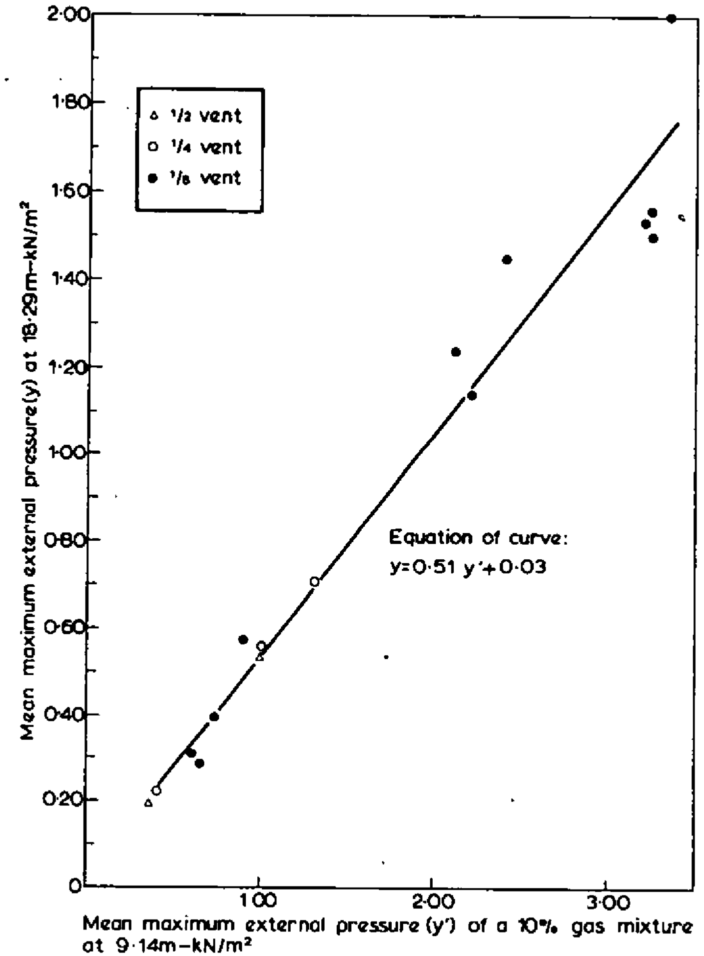

Figure 4 Relation between explosion pressure at two sites external and normal to vent

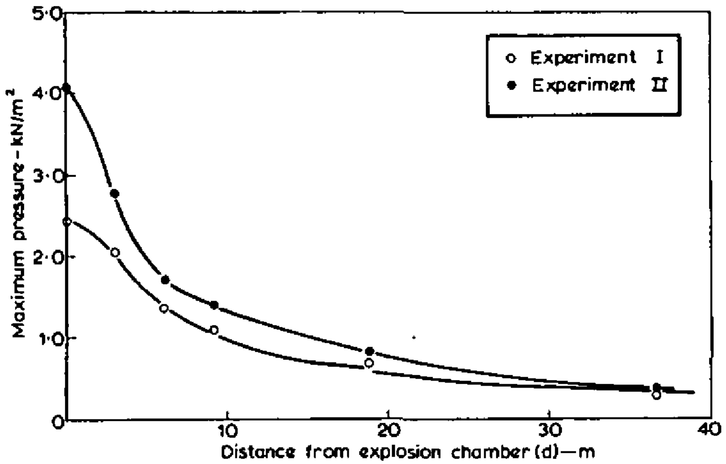

Figure 5 Effect of distance from explosion chamber on maximum pressure

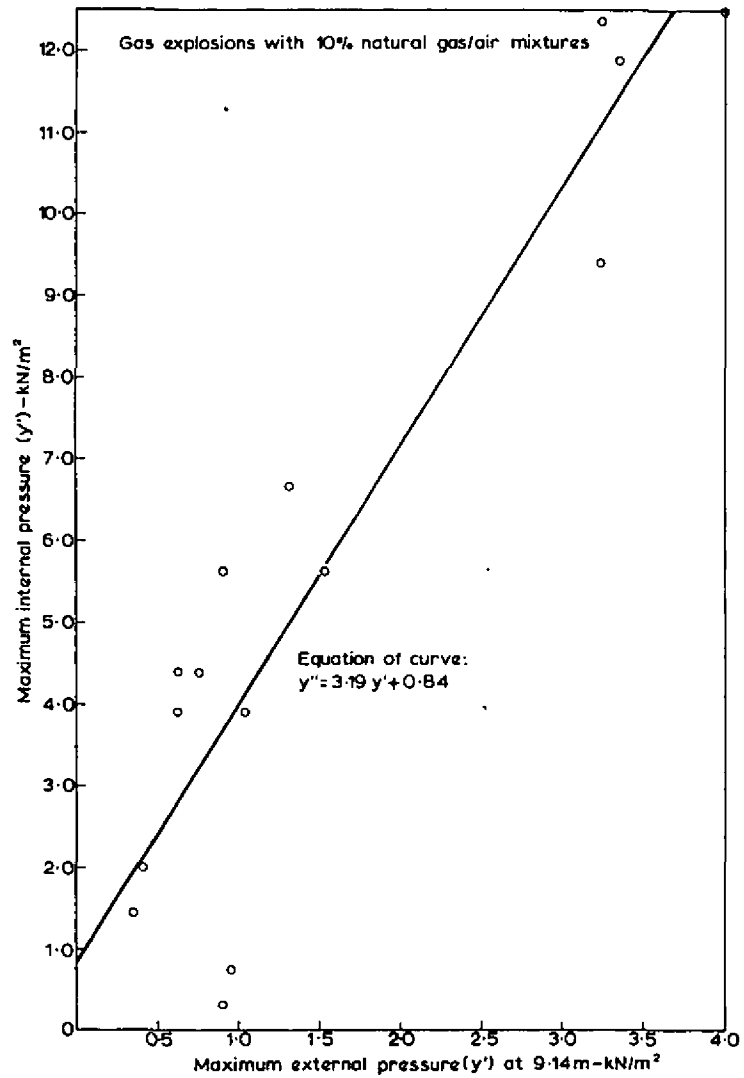

Figure 6 Relationship between external maximum pressure and maximum pressure within chamber

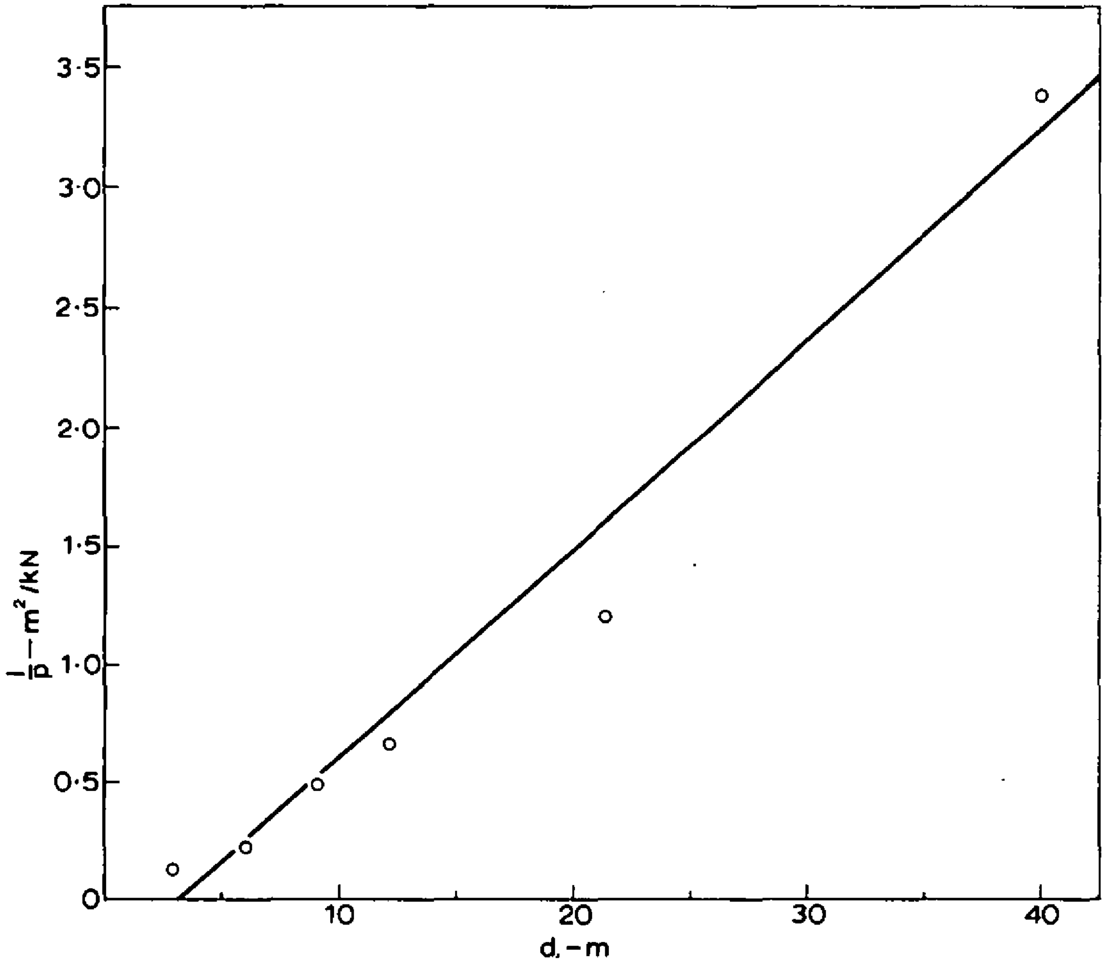

Figure 7 Relation between reciprocal of maximum external pressure and distance from front of chamber

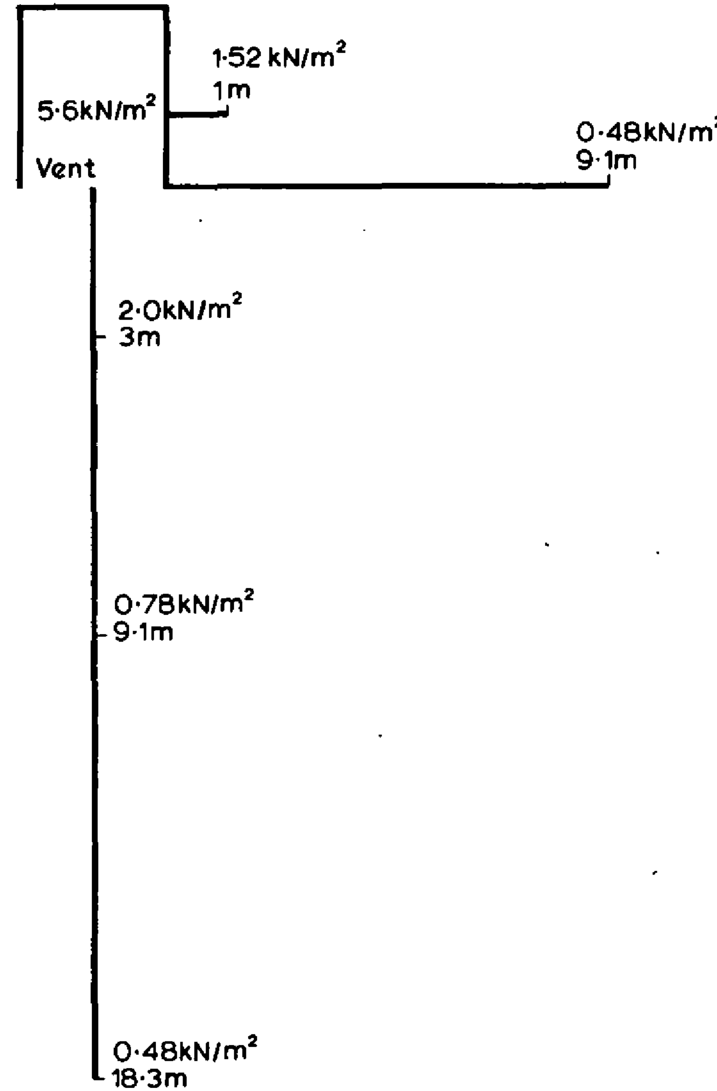

Figure 8 Distribution of maximum pressure for experiment with 0·61m layer of stoichiometric natural gas/ air mixture with 1/8 vent

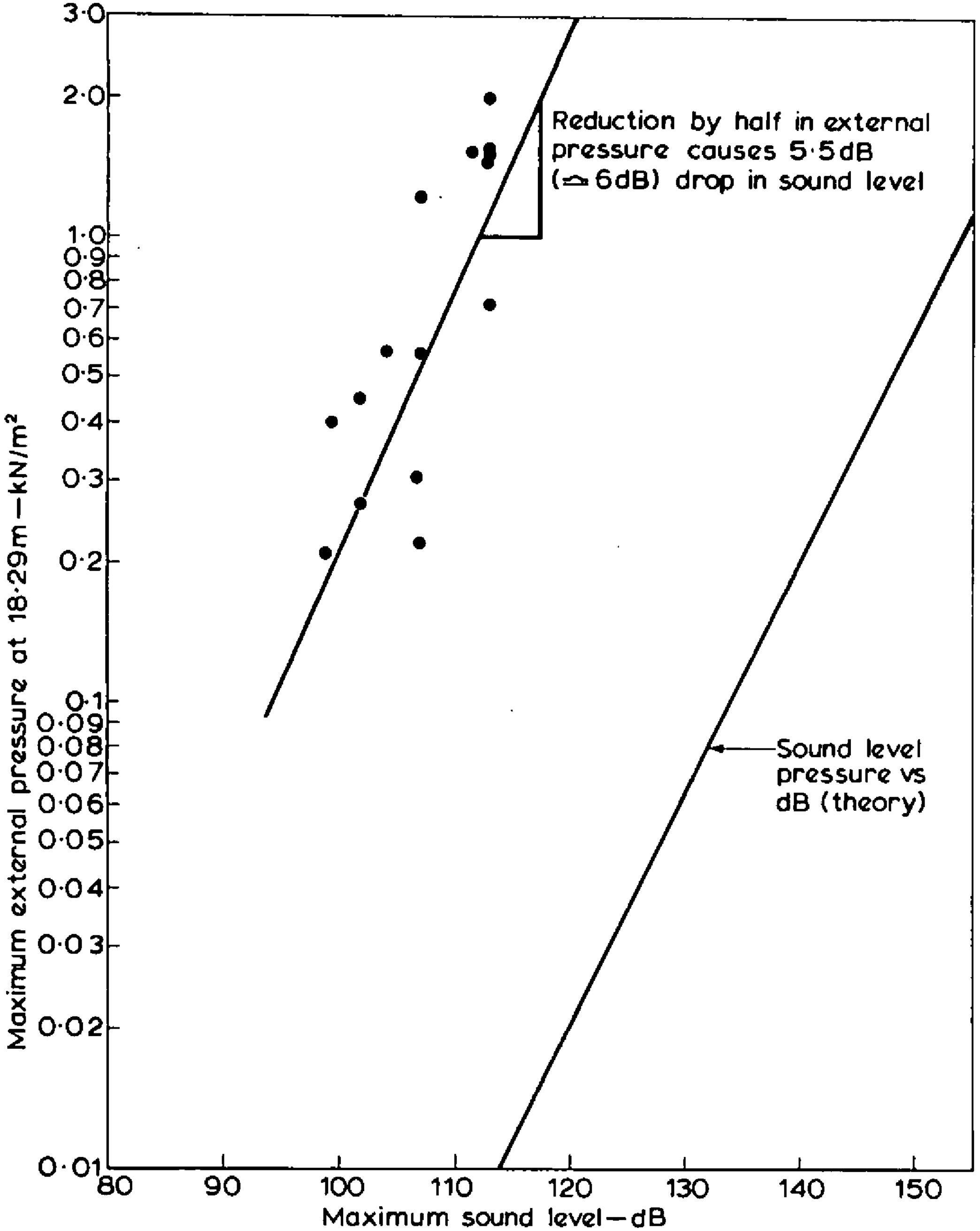

Figure 9 Relationship between sound level (dB, A network) and maximum explosion pressure

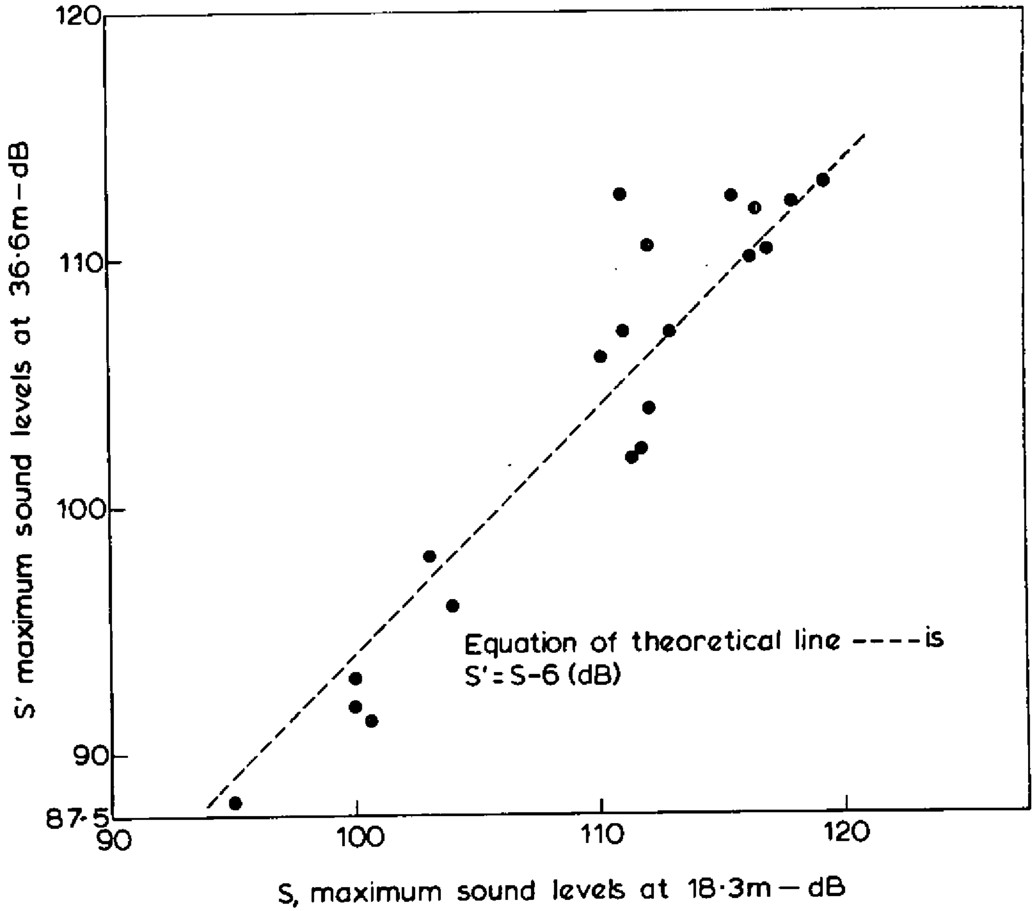

Figure 10 Sound levels (dB) at 18·3m vs 36·6m of gas explosions with 1/2 vent

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