Table 3. Characteristics of the reaction zone of industrial explosives.

No.		1	2	3	4
Kind of explosive		Permitted Powdery Dynamite	Permitted Ammon Explosive	Semi-gelatin	Ammon Gelatin
t=Reaction time μ sec	Critical t_c	2.00	1.73	2.53	0.86
	First transition t_1	–	6.26	5.33	4.06
	Second transition t_2	–	–	7.66	–
	Maximum t_m	16.9	11.7	13.5	8.19
	t_m/t_c	8.45	6.76	5.38	9.52
Fraction of heat $N=Q_e/Q_m$	N_c	0.115	0.163	0.105	0.080
	N_1	–	0.664	0.218	0.335
	N_2	–	–	–	–
X=Reaction zone length cm	X_c	0.23	0.297	0.355	0.146
	X_1	–	2.14	1.08	1.41
	X_2	–	–	2.67	–
	X_m	5.71	4.93	5.86	4.92
	X_m/X_c	24.8	16.6	16.5	33.6
	X_c/R_e	0.66	0.69	1.02	0.27
	X_m/R_u	1.39	1.37	1.52	1.27

HOLLOW STRUCTURE OF EXPLOSION FRONT OF METHANE-AIR MIXTURE IGNITED BY EXPLOSIVES

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by Kumao Hino* and Seiichi Hasegawa

Introduction

Explosion of methane-air mixtures has been widely investigated by means of photographic methods by various authors,1)2)3)4) however, the observations have been conducted on one side of explosion chambers while the structures of ignition zones and propagation fronts have three dimentional characteristics which sometimes lead to misinterpretation of explosion phenomena when they are one-dimentionally observed. For example we have assumed solid disk shape of propagation front while actually it was ring shape front, and we have assumed solid cylindrical front of propagation while actually it was only an ignition on a wall of a chamber. This fundamental defect of the photographic observation which can give only superficial properties of phenomena may be removed when we observe an explosion from two sides. In the present paper the explosion of methane-air mixture has been observed in a transparent plastic chamber both from an end and a side by means of a reflecting mirror and recorded by 16mm Kodak High Speed Camera. Change of pressure during an explosion has also been recorded by a condenser type pressure gauge with an autodyne recording apparatus to get information on explosion which may be not necessarily luminous.

Experimental

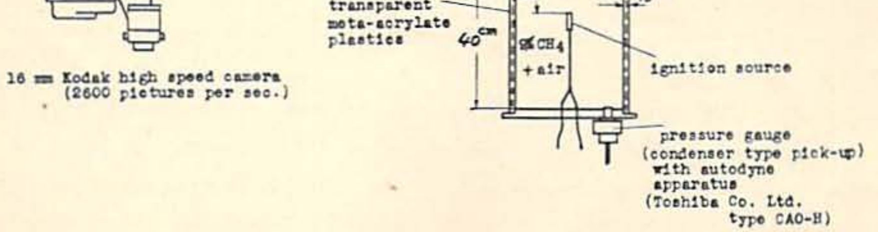
1. Pressure measurement

Experimental arrangement is described in Fig. 1. The results of measurement of pressure-rise during explosion is shown in Fig. 2. The results are summarized in Table 1. It shows that there are great differences between the maximum rates of rise of pressure with different sources of ignition, that is (1) fused platinum wire (2) ignition head of electric detonator, (3) electric detonator with

Table 1. Maximum rate of rise of explosion pressure for four ifferent sources of ignition with 9% CH_4+air

No.	Ignition source	Maximum rate of rise of pressure of explosion	Maximum explosion pressure	Characteristics of ignition source
		kg/cm²/m sec.	kg/cm²	
(1)	Fused Pt wire	0.082	5.5	diameter 0.03mm length 2mm resistance 0.8ohm condenser discharge 280 volt 1 micro farad
(2)	Ignition head of electric detonator	0.10	6.6	10 milligram of lead dinitroso-resorcinate+lead rhodanate +potassium chlorate
(3)	Electric detonator with $Hg(CNO)_2$+$KClO_3$	0.37	7.1	Total charge 0.6 gram in paper shell pressed to 30kg
(4)	Electric detonator with tricinate	0.92	7.5	Total charge 0.5 gram in paper shell

Fig. 1. Arrangement for twoside photographic observation



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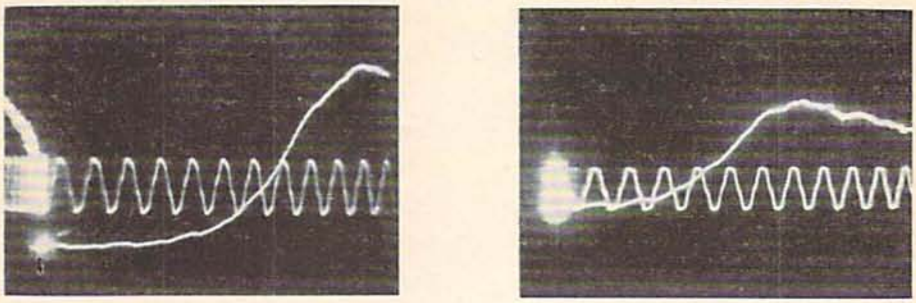
mercury fulminate mixed with potassium chlorate (8 : 2) and (4) electric detonator with tricinate, (trinitroresorcinate of lead) although maximum explosion pressures are $6 \sim 7 \mathrm{kg/cm^2}$ for four cases.

2. Ignition probability by suspended detonator


(1) Fused platinum wire
(2) Ignition head

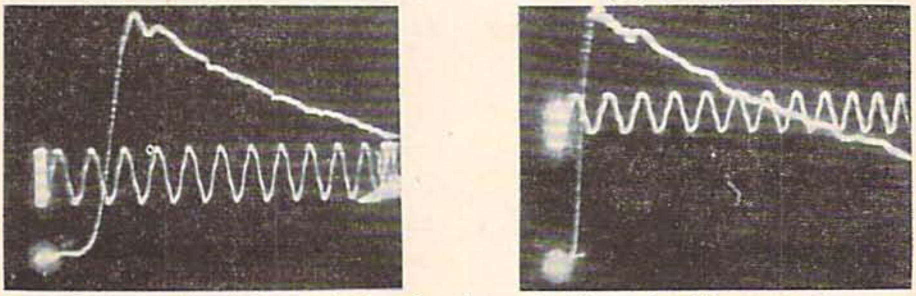

(3) Mercury fulminate detonator
(4) Tricinate detonator

Fig. 2. Pressure rise during explosion of methane air mixture by different ignition source. Calibration frequency 60/sec. one wave length 16.6m sec.

Probability of ignition by a suspended electric detonator with 0.6, 0.4, and 0.2 grams of mercury fulminate, potassium chlorate mixtures respectively has been investigated with various distances between an end-wall of a chamber and a base of a detonator. The results are summarized in Fig. 3. which shows that (1) increase of charge increases the chance of ignition (2) decrease of distance *d* between a wall and an ignition source increases the ignition probability while at extremely short distance the ignition probability decreases.

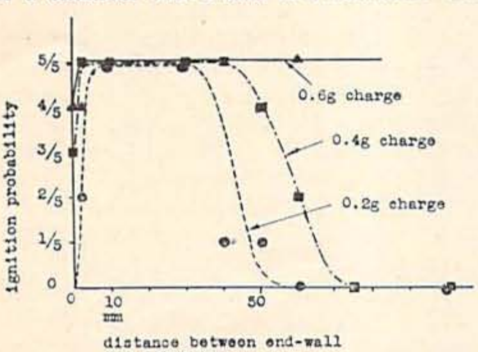


Fig. 3. Ignition probability for different weight of charge of electric detonator with various distance *d* mm between end-wall and detonator

3. Propagation of explosion from suspended detonator

Fig. 4. shows the development of explosion within 9% methane-air mixture ignited by a 0.4g fulminate paper detonator. Distance between an end wall and a detonator base is 60mm. An Origin of an explosion of mixture seems not to be the detonation center of a detonator but to be fragmental sections of a corner of a chamber, which may be called

ignition islands. The explosion origins then increase in size not only along the bottom periphery but also along the side wall of a chamber, that is, the explosion front has a hollow structure and not a solid zone. Wall seems to have a great influence not only on the ignition but also on propagation. This type of development may be briefly described as follows:

Mode (1) center detonation, ignition islands in a corner, ignition band in a corner, cylindrical wall propagation.

Fig. 5. shows the sequence of events for smaller distance (d=30mm) between an end-wall and a detonator which may be summarized as follows:

Mode (2) near end-wall detonation, central ignition of methane air mixture, propagation of an explosion in space (not on a wall).

In this case the space between a detonation point of a detonator and an end-wall provides an ignition source of enough intensity, duration and size while in mode (1) the detonation point is too small in size, and too short in its duration although it may be intense. The corner fulfils the three conditions for ignition, that is, long duration enough size and enough intensity probably produced by shock wave reflections, shock wave co-operation and adiabatic compression.

Fig. 6. shows another mode of explosion where a detonation point becomes nearer to an end-wall (d=10mm). The igition occurs as follows:

Mode (3) detonation extremely near an end-wall, ignition of methane air mixture between detonation point and an end-wall, shift of ignition islands or centers to the corner of a chamber, propagation of an explosion along a cylindrical wall of a chamber.

The shift of central ignition zones to the corner may be produced by strong flow from the detonation point toward the the corner. As in the mode (1) the explosion front develops as a hollow cylinder although the way of its initiation is different between the mode (1) and (3).

Fig. 7. shows another mode (4) of central ignition (d=200mm) by a tricinate detonator which contains 0.4 grams of trinitro-resorcinate of lead. As the intensity of detonation is much higher than that of mercury fulminate potassium chlorate mixture the ignition of methane air mixture occurs at a detonation point.

Conclusion

When the intensity of an ignition source is not strong enough to ignite 9% methane-air mixture at a detonation point of a detonator, ignition occurs in a corner of a chamber and an explosion front develops on a wall of a chamber and not in space, that is, it has a hollow structure.

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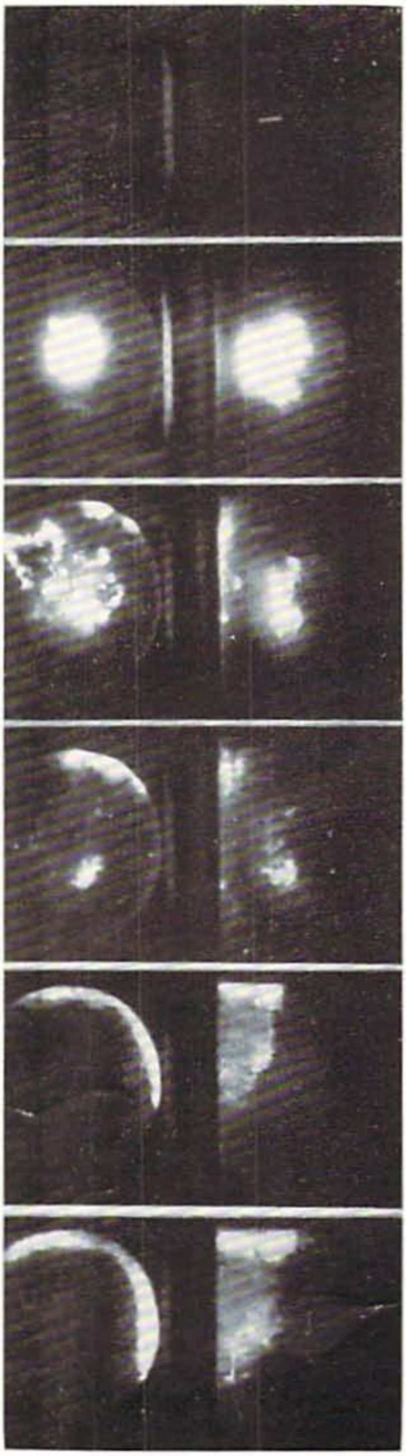


(1) Before detonation

(2) Detonation of detonator 0m sec

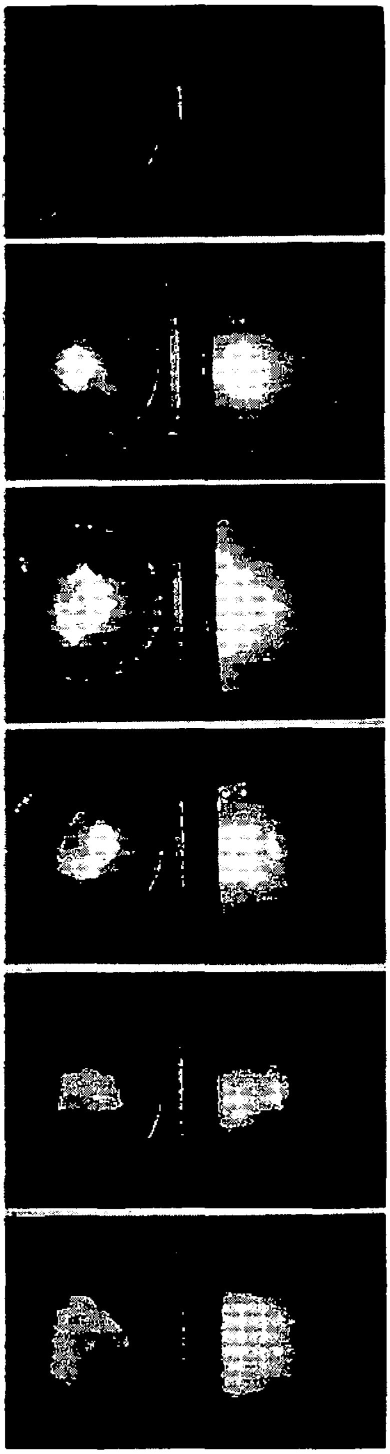
(3) Ignition of methane-air (Island ignition)
0.77m sec

(4) Growth of ignition island along periphery
1.54m sec

(5) Growth of ignition zone both along
periphery and cylinder wall
7.70m sec

(6) Further cylindrical wall propagation
11.5m sec

Fig. 4. Ignition and propagation of explosion in methane-air by 0.4g fulminate detonator (d=60mm)



(1) Before detonation

(2) Detonation of detonator 0m sec

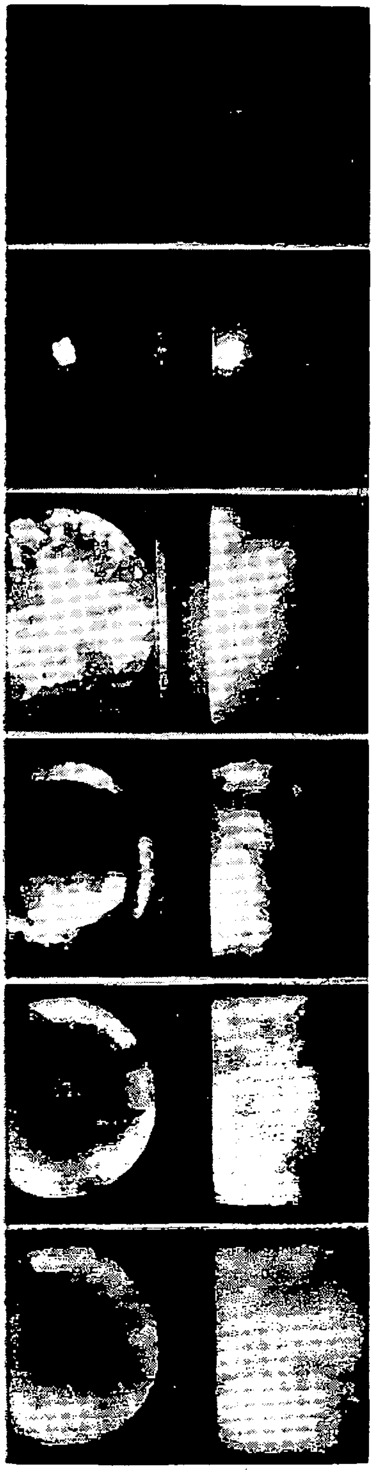
(3) Ignition of methane-air near-end-wall center ignition 1.15m sec

(4) 2.31m sec

(5) 7.70m sec

(6) 11.5m sec

Fig. 5. Ignition and propagation of explosion in methane-air by 0.4g fulminate detonator (d=30mm)



(1) Before detonation

(2) Detonation of detonator 0m sec

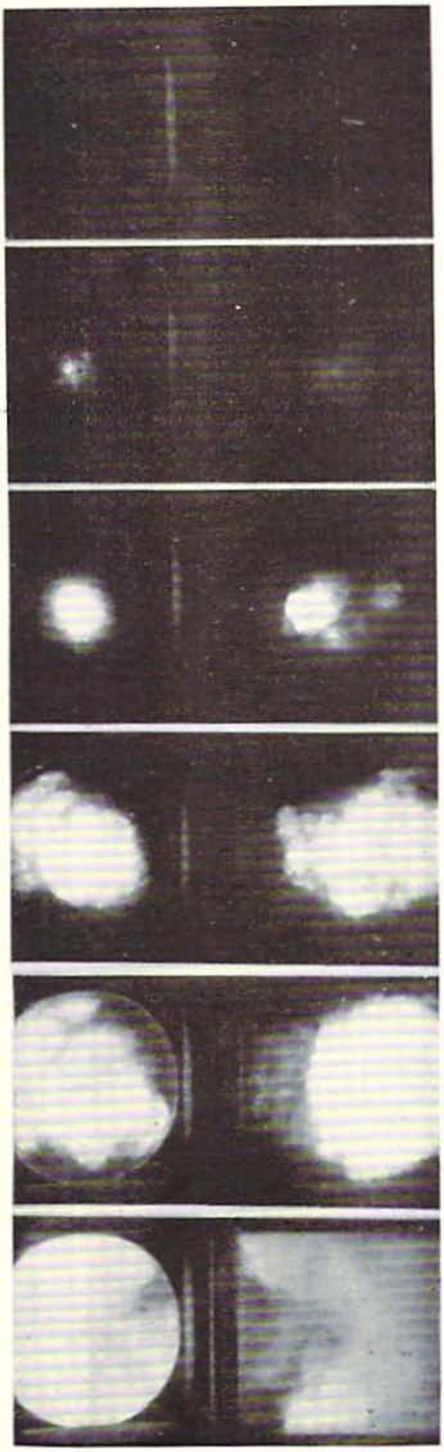
(3) Ignition of methane-air central islands
ignition 0.77m sec

(4) Shift of central islands to periphery
3.90m sec

(5) Growth of ignition zone along periphery
and cylinder wall 7.70m sec

(6) Further cylindrical wall propagation
11.5m sec

Fig. 6. Ignition and propagation of explosion in methane-air by 0.4g fulminate detonator (d=10mm)



(1) Before detonation

(2) Detonation of detonator
0m sec

(3) Ignition of methane-air central ignition
0.39m sec

(4) Propagation of explosion from center
2.31m sec

(5) Further propagation
3.00m sec

(6) Full explosion
11.5m sec

Fig. 7. Ignition and propagation of explosion in methane-air by 0.5g tricinate detonator ($d=200$mm)