Reports of the Academy of Sciences of the USSR

R. I. SOLOUKHIN

1961

SovietRxiv

Figure 1

Figure 1: Figure 1

Abstract

Full Text

Reports of the Academy of Sciences of the USSR
1961. Vol. 136, No. 2

HYDROMECHANICS

R. I. SOLOUKHIN

ON THE BUBBLE MECHANISM OF SHOCK IGNITION IN A LIQUID

(Presented by Academician M. A. Lavrent’ev, 2 VIII 1960)

In the well-known experiments on shock ignition in liquid explosives (^{1}), it was found that the sensitivity to explosion is determined to a large extent by the presence of gas bubbles in the volume of the liquid. Under the action of a sharp increase in the external pressure, adiabatic collapse of the bubble occurs, which leads to the formation of an ignition center in the gaseous medium. Estimates of the maximum gas temperature by the formula for adiabatic compression up to the excess pressure in the liquid cannot be considered correct because of the inertial nature of the bubble-collapse process. The collapse time may also prove to be a quantity of the same order as the time over which the pressure behind the shock wave in the liquid producing the compression changes appreciably. This causes additional difficulties in calculating the compression. Below we consider the results of experiments on shock ignition of explosive gas mixtures enclosed in the form of bubbles in water.

Fig. 1. Oscillogram of the pressure of a shock wave in water. Time marks: 10 μsec

The shock wave was produced by an electrical discharge of a capacitor of capacitance 100 μF, charged to 900 V, through a bridge 3 mm long made of thin nichrome wire in water. An oscillogram of the wave pressure, recorded at the location of the bubble, is shown in Fig. 1. The pressure was recorded on an OK-25 oscilloscope by a pulsed piezoelectric transducer with a sensing element made of barium titanate ceramic, 13 mm in diameter and 11 mm high.

Figure 2 shows a time sweep of the motion of the bubble wall during ignition of a mixture of $C_2H_2 + O_2$. The photograph was taken by the shadow method on rotating motion-picture film through a narrow slit parallel to the direction of motion of the shock wave. The image also shows the contour of the gas bubble from the electric explosion. From the photographic sweep the time of compression and expansion, the minimum radius of the bubble, and also the ignition of the gas are determined.

The initial phase of compression is analogous to the process of compression of an inert gas because of the finite induction period of ignition. Therefore the law of motion of the wall of a single gas bubble under the action of an external pressure varying in time can be described by the equation for an infinite incompressible liquid (of the Lamb type) in the form:

$$\rho\left[r\frac{d^2r}{dt^2}+\frac{3}{2}\left(\frac{dr}{dt}\right)^2\right]=p_\infty(t)-p_0\left(\frac{r_0}{r}\right)^{3\gamma},$$

taking $p_\infty(t)$ to be the pressure behind the shock-wave front, if the length of the shock wave is sufficiently large compared with the bubble diameter. In Fig. 3

To the article by R. I. Soloukhin, p. 311

Fig. 2. Sweep record of the motion of the bubble wall during ignition of the mixture $C_2H_2 + O_2$; $d_0 = 8$ mm

To the article by L. I. Karyakina and A. T. Zelenskaya, p. 434

Fig. 1. Quartz porphyry. In the fine-grained groundmass, quartz inclusions (white) with a rim consisting of small quartz grains are visible. With analyzer, 80×

Fig. 2. Elutriated finely dispersed particles of quartz porphyry. Isometric flakes—kaolinite; tubes—halloysite

Fig. 3. Quartz porphyry after heating at 1650°. Quartz inclusions that have transformed into scaly anisotropic cristobalite (a), surrounded by rims of fine-grained needle-like cristobalite (b). Without analyzer, 250×

Fig. 4. Quartz porphyry after heating at 1650°. Black areas—former inclusions of fused feldspar, surrounded by needle-like mullite. The gray large area—former quartz inclusion, transformed into scaly cristobalite and surrounded by a dark rim of needle-like cristobalite. White areas—glassy substance. Without analyzer, 180×

DAN, vol. 136, No. 2

the results of the numerical solution of this equation are given for the case: $\gamma = 1.4$; $p_0 = 1$ atm.; $p_\infty = 10p_0e^{-t/\tau}$; $\tau = 10^{-4}$ sec.; $2r_0 = 3.5$ mm. The experimental curve of the change in the radius of an air bubble with time, obtained under conditions close to the calculated ones, is also shown there. Some discrepancy with the calculation can be explained by the presence of a thin (0.03 mm) rubber shell limiting the volume of gas in the bubble.

Fig. 3. Comparison of the calculation of the motion of the wall of an air bubble with experiment. 1 —calculated graph, 2 —experimental curve

Figure 2: Fig. 3. Comparison of the calculation of the motion of the wall of an air bubble with experiment. 1 —calculated graph, 2 —experimental curve

Following the rapid compression of the gas volume, it undergoes sharp cooling as a result of expansion (pulsation of the bubble). If, in this case, the maximum temperature corresponds to an induction period longer than the expansion time, ignition does not occur. Thus, for a mixture of hydrogen with oxygen, the ignition temperature under adiabatic compression ([2]) lies within the range 800 –1200°K, in accordance with the magnitude of the induction period. The self-ignition temperature of the mixture $2H_2 + O_2$ in the experiments described is 891 ± 15°K, which corresponds to an induction period of less than 50 μsec.

Fig. 3. Comparison of the calculation of the motion of the wall of an air bubble with experiment. 1 —calculated graph, 2 —experimental curve.

The author expresses his gratitude to A. I. Gol' binder, who pointed out the practical interest of the questions considered.

Institute of Hydrodynamics
Siberian Branch of the Academy of Sciences of the USSR

Received
27 VII 1960

CITED LITERATURE

1. F. P. Bowden, A. D. Ioffe, *Initiation and Development of Explosion in Solid and Liquid Substances*, IL, 1955.
2. S. G. Zaitsev, R. I. Soloukhin, DAN, **122**, No. 6, 1039 (1958).

Note: Figure translations are in progress. See original paper for figures.