INITIATION OF LIQUID EXPLOSIVES BY CAVITATION

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It is known that in some circumstances liquid explosives can be initiated with unexpected ease, and in other circumstances only with great difficulty.

Thus, Winning [1] has shown that nitroglycerine (NG) free of gaseous inclusions and poured into a vessel so as to leave no wall surfaces free of liquid is not exploded even by the action of a fairly strong shock wave from a detonator immersed in the NG.

On the other hand, in handling liquid explosives there have been quite a few cases in which relatively weak vibrations or impacts have led to unexpected explosions, which have sometimes had serious consequences. For example, a British report [2] describes an unfortunate accident that resulted from dropping a polyethylene bottle containing NG. Upon hitting the ground the NG exploded.

The initiation of explosion by "hot spots" resulting from the adiabatic compression of gaseous inclusions even before the arrival of the shock wave has been reliably demonstrated in numerous experiments [1, 3]. However, some cases of initiation of liquid explosives simply cannot be attributed to the heating of such gaseous inclusions, since in these cases the adiabatic compression temperatures of the gas are so small that it is not possible to talk of a "hot spot." Such puzzling cases include, for example, the above-mentioned explosion of NG in a polyethylene bottle. In other experiments [4] the role of gaseous inclusions has been completely eliminated by first subjecting the liquid explosive to a constant high pressure. This so reduced the degree of compression of the gaseous inclusions by a weak shock that strong heating of the gas in the bubbles, if any were present in the liquid explosives, was completely excluded. Nonetheless, there was no reduction in the sensitivity of the explosive to weak shocks.

In attempting to explain such puzzling cases it is usually pointed out that explosion can be initiated by cavitation [1, 5], which may develop in a liquid even as a result of a weak impact or vibration. So far, however, no one has offered any direct experimental evidence of the possibility of cavitational initiation of explosion in liquid explosives. The object of our research was to fill that gap.

1. Cavitation in liquid explosives due to weak impact. In most real liquids cavitation is already observable at negative pressures equal to a few tenths of an atmosphere. This process is assisted by the microscopic bubbles of gas usually present in the liquid, solid surfaces that are not easily wetted, and also cavitation nuclei created by cosmic radiation [6].

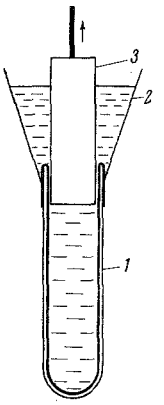

Fig. 2

Figure 1 presents frames obtained with a high-speed motion-picture camera showing the behavior of a stoichiometric solution of benzene in tetranitromethane (TNM) in a freely suspended glass test tube, the bottom of which was struck by a copper plate projected at a speed of about 5 m/sec.

In the first frame the liquid is still motionless, in the second a few bubbles have already appeared, and in the third their number has increased and dark transverse bars have become visible, the latter being discontinuities that have not had time to expand and acquire a spherical shape. In the fourth frame all the bars have disappeared (collapse), and at the surface the liquid has begun to spout.

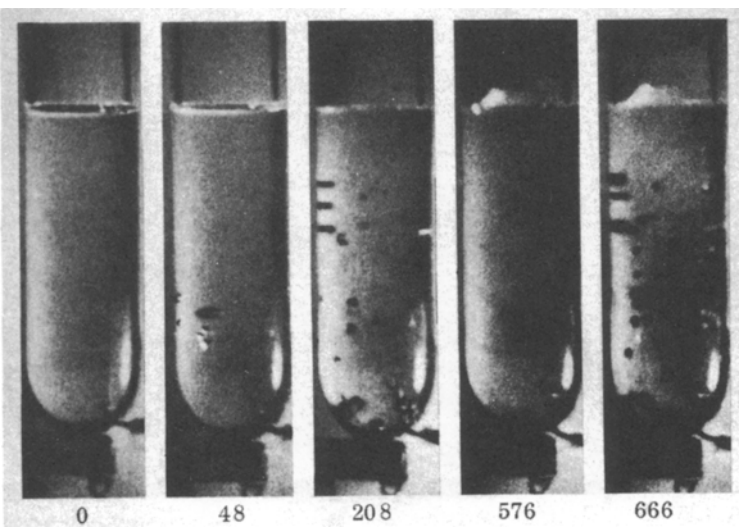

Fig. 1

The last frame discloses an even greater number of cavities, some of which have developed approximately at the previous sites. Spouting continues.

Each frame was exposed for 8 μsec. The figures beneath the frames denote the time in μsec from the instant of exposure to the instant at which the plate touched the test tube. In most cases the outside diameter of the test tube was 15 mm, and the wall thickness 1.5 mm (the test tube usually broke, but in this experiment it remained intact and was not even cracked). The experiment whose results are presented in Fig. 1 merely indicates the occurrence of cavitation following a relatively weak impact against the vessel containing the liquid. In this case collapse of the bubbles did not lead to initiation of the very sensitive explosive—benzene in TMN at stoichiometric concentration.

The same fine cavitation bubbles also developed in a solution of benzene in TNM when an electric discharge, releasing an energy of about 70 J in the course of 10 μsec, was triggered in a layer of water poured into the test tube above the solution (20 mm from the surface of the solution). Cavitation did not create an explosion in this case either.

2. Cavitation with a fairly stable initiating capacity. Cavitation bubbles by means of which it proved possible to initiate explosions in solutions of benzene and heptane in TNM were created by the negative pressure pulse resulting from the withdrawal of a piston immersed in the solution.

The device used in these experiments consisted of a glass test tube 1 with a length of 8–9 cm, outside diameter 15 mm, and wall thickness 1.5 mm (Fig. 2). A small conical funnel 2, made of twisted foil, was fitted over the top of the tube and secured with insulating tape. The test liquid was poured into the tube to a level slightly above its edge, and then the piston 3 was inserted to a depth of 1–3 cm, which displaced another portion of the liquid into the funnel. When the piston was withdrawn sharply from the test tube (using a heavily loaded steel bow made from one leaf of a car spring) a negative pressure pulse traveled down to the bottom of the tube. Upon reflection of the pulse from the bottom the tensile force increased somewhat and the liquid separated from the bottom, at the same time parting at other points and forming cavitation cavities of various shapes.

As the piston moved upward, creating behind it a vapor-filled space, the pressure beneath it could not become higher than the saturated vapor pressure of the liquid, since atmospheric air could not penetrate under the piston, being blocked by the liquid in the funnel. Transmission of atmospheric pressure through the liquid in the narrow gap between the piston and the walls of the tube can be neglected.

Cavitation cavities appeared in the test tube even when the piston had just begun to move upward. Its velocity in the test tube reached 10 m/sec at the end of the first millisecond. In the course of the few milliseconds required for the piston to leave test tube, and for the liquid in the funnel almost completely to fill the space left behind it under the influence of atmospheric pressure, these cavities continuously increased in size, so that some of them sometimes acquired a diameter close to that of the test tube. Then, when the liquid from the funnel encountered the liquid in the test tube, the pressure in it rose sharply, hydraulic impact occurred, and the slow growth of the cavitation bubbles became a rapid collapse. The collapse process lasted about 100 μsec.

At the instant of hydraulic impact near the bottom of the test tube the pressure in the liquid, p_a, measured with a barium titanate miniature hydrophone, varied from experiment to experiment from a few to several tens of atmospheres. It was the higher, the more deeply the piston was immersed in the test tube. At an immersion depth greater than 3 cm the glass test tubes used in the experiments were usually destroyed by the hydraulic impact. The strength of their walls may be judged from the fact that sealed test tubes containing a small amount of water broke upon being heated to 280° C, i.e., at a steam pressure of about 70 atm.

Cavitation bubbles did not occur if before the experiment air bubbles were applied to the end face of the piston immersed in the liquid. In this case rapid expansion of the bubble caused premature separation of the surface of the piston from the liquid which reduced the tensile force. The largest cavities were obtained when the gap between the piston and the test tube walls was about 0.05 mm (for liquids with a viscosity close to the viscosity of water), and the surface of the piston was wetted by the liquid better than the surface of the test tube. These conditions may even lead to total separation of the liquid from the bottom of the test tube.

If the piston was made of lucite or beechwood, this wettability condition was well satisfied for solutions of benzene and heptane in TNM and for NG, but was not satisfied when methanol or a solution of methanol in TNM was used as the test liquid. Methanol does not form a contact angle on glass, but creeps continuously over it, and the adhesion between the glass and the methanol is stronger than the cohesion of the methanol itself. In other words, it is easier to rupture the methanol than separate it from the surface of the glass. In a test tube containing methanol, cavitation did not occur close to the bottom of the tube even if the piston was also made of glass. In this case a single large bubble was usually formed in the middle of the column of liquid.

The collapse of cavitation cavities in a solution of benzene in TNM is shown in Fig. 3. The exposure was about 8 μsec for each frame. In this case, too, the upper part of the test tube had a diameter of 15 mm. The figures beneath the frames denote the time in microseconds between the instant of exposure and the

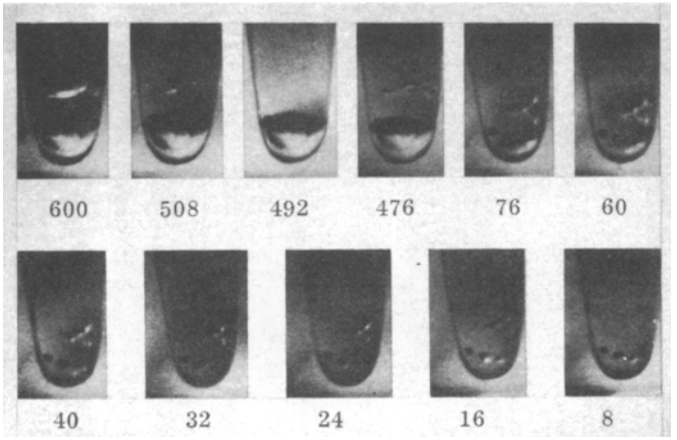

Fig. 3

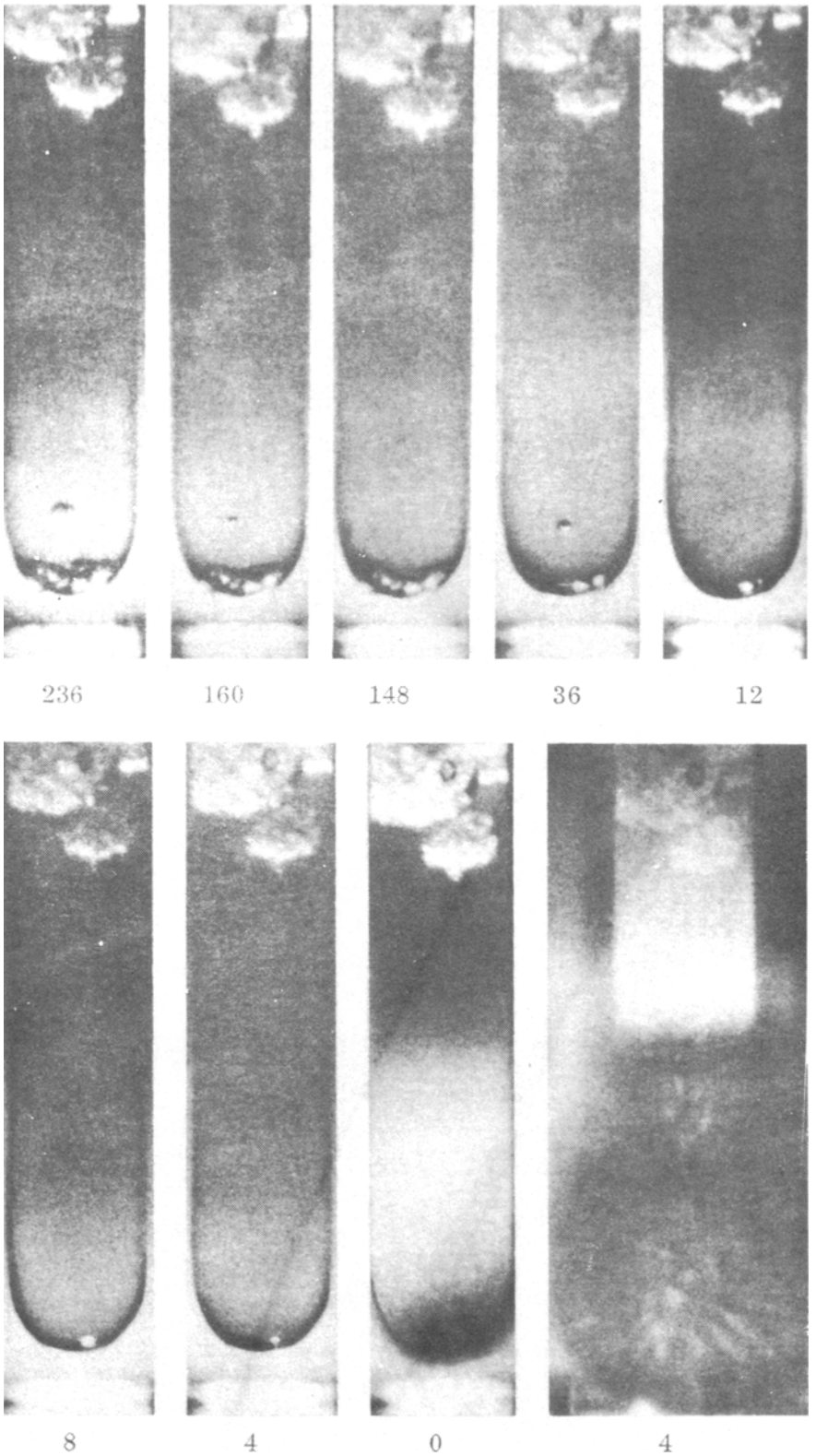

Fig. 4

moment of explosion due to collapse of the cavitation bubbles near the bottom of the test tube. At this point the piston was 3–4 cm above the upper edge of the test tube, i.e., outside the liquid. The photographs clearly show the behavior of the cavities in the liquid when the piston is withdrawn. Some of them now disappear, now reappear, and finally four small bubbles of fairly regular sperical shape are formed in the test tube. The last frame of this series directly precedes explosion, which occurred in the solution near the bottom of the tube.

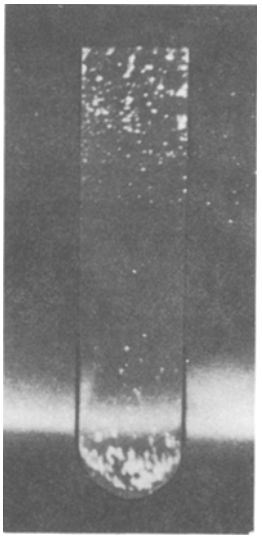

Fig. 5

The initiation and propagation of detonation in a solution of benzene in TNM is illustrated in Fig. 4. In this case the exposure time did not exceed 4 μsec for each frame. The moment of explosion is registered on the penultimate frame. On the positive the site of the explosion appears particularly dark owing to overexposure of the negative up to the point of solarization of the emulsion owing to coincidence of the bright flash of the explosion and the equally bright light of the IFK-20 flash lamp used to illuminate the bottom of the tube. Since detonation was propagated at high speed (about 7.5 km/sec), at the above-mentioned exposure a sufficiently sharp image of the detonation front could not be obtained on the photograph. The expansion of the detonation products is already visible in the last frame. The photographs were obtained with a ZhLV-2 slave time magnifier designed and built at the Institute of the Physics of the Earth of the Academy of Sciences USSR and the Krasnogorsk Mechanical Plant [7]. As already indicated, the test tube containing the liquid was illuminated against a white background by an IFK-20 flash lamp, and the light reflected from the cavitation cavities was registered on film to give a picture of the cavitating liquid.

In the experiments with solutions of benzene or heptane in TNM, cavitation always occurred. Bubbles (especially near the bottom of the tube) began to form and grow rapidly after the tension wave reached and was reflected from the bottom. In the case of a solution of benzene in TNM at stoichiometric concentration, explosions (primarily at the very bottom of the tube) occurred most frequently, but on average not more frequently than in one experiment out of three. Deviation from stoichiometric concentration led to a reduction of the number of experiments ending in explosion. The region of volumetric ratios of TNM to benzene β, in which cavitation could still cause an explosion, was not wide (from $\beta = 3 : 1$ to $\beta = 4.5 : 1$). The stoichiometric concentration corresponds to $\beta = 3.4 : 1$. Consequently, the region of concentrations of lean solutions sensitive to cavitation is somewhat broader than the corresponding region of rich solutions.

Very occasionally, when especially large bubbles were formed remote from the bottom of the tube, an explosion occurred when they collapsed, propagating upward and downward through the tube, so that the bubbles in the bottom of the tube were unable to collapse before the detonation wave reached them.

In the photographs it is possible to distinguish only those objects whose actual dimensions exceeded 0.1 mm. Therefore, it was impos-

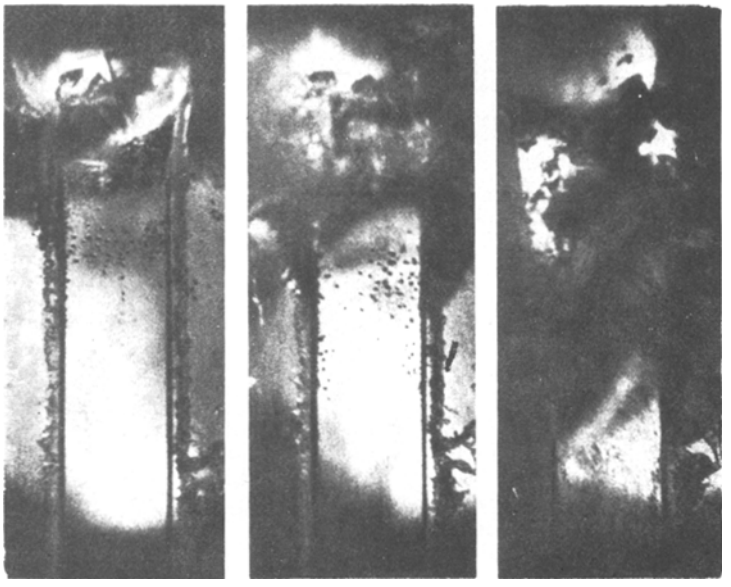

Fig. 6

sible to estimate the degree of compression of the bubbles from their images.

In the experiments we usually employed pistons made of lucite or beechwood, whose friction against the glass could not lead to particularly high temperatures [8]. In all the experiments the center of explosion was located below the level of the initial position of the end face of the piston in the tube. This also indicates that friction could not be the cause of the explosion. Cavitational initiation of explosion close to the bottom of the tube occurred even when the length of the tube reached 25 cm, and the depth of immersion of the piston was only 1 cm.

A solution of heptane in TNM proved to be much less sensitive to cavitation than a benzene solution. Out of fifty experiments, precisely analogous to the experiments with benzene solutions, only two ended in explosion, and in one of these detonation in a stoichiometric solution of heptane in TNM occurred only after a stage of transition from combustion to detonation lasting about 10 μsec. In numerous experiments with solutions of benzene in TNM this effect was never observed.

Solutions of methanol in TNM did not explode even upon the collapse of very large cavitation cavities whose diameter approached the diameter of the tube. Equally unsuccessful were attempts to initiate an explosion by cavitation in a solution of methane in liquid oxygen cooled to the boiling point of liquid nitrogen, and also in acetylene frozen in a test tube containing liquid oxygen at the same temperature.

The vapor pressures measured above stoichiometric solutions of heptane, benzene, and methanol in TNM were approximately 15, 30, and 60 mm Hg, respectively. The vapor pressure above NG was $2.5 \cdot 10^{-4}$ mm Hg, and above a solution of methane in liquid oxygen about 70 mm Hg.

In NG cavitation bubbles occurred in large numbers, but their dimensions were somewhat smaller than, for example, in a solution of benzene in TNM.

In none of the experiments in which a piston (lucite) with a plane end face was used did the NG explode. But it was only necessary to give the end of the same piston a conical shape for the NG to explode when it was withdrawn (almost always at the first or second attempt).

The angle at the apex of the cone usually did not exceed 60°, and in this case the piston looked like a sharpened pencil. The center of explosion was always located in the upper part of the tube, in the region occupied by the conical part of the piston before withdrawal.

When NG was replaced with solutions of benzene or heptane or methanol in TNM attempts to cause an explosion in the upper part of the tube by means of a piston with a conical end were unsuccessful.

3. State of vapor (gas) in collapsing cavitation bubble. The behavior of an empty spherical cavity in an ideal incompressible fluid subjected to a constant pressure at an infinite distance from the cavity was investigated by Rayleigh [9].

The collapse time for such a cavity

$$\tau = 0.915\ R_0\ (\rho/p_a)^{1/2}. \qquad (3.1)$$

Here, R_0 is the initial radius of the cavity, p_a the pressure in the liquid under which the cavity collapses, and ρ the density of the liquid surrounding the cavity.

The bubbles that occur in real liquids possessing viscosity, thermal conductivity, compressibility, and surface tension, are usually filled with a certain amount of vapor or gas. Numerous theoretical and experimental studies (see, for example, [10, 11]) have shown that the greatest retarding influence on the process of collapse of such a cavity is exerted by the vapor it contains (sometimes with a small admixture of the gas dissolved in the liquid), while the role of viscosity (if it is not more than 100 times greater than the viscosity of water), compressibility, and surface tension is not especially important and is effective only in the concluding stage of collapse, when the dimensions of the bubble become so small, and the velocity of its walls so great, that experimental verification of the theoretical data becomes almost impossible.

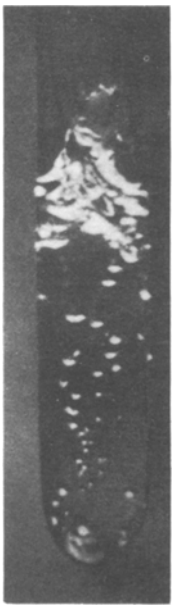

Fig. 7

Cavitation bubbles that occur close to the walls of the vessel (or directly on the walls) should collapse more slowly than those formed at a considerable distance from the walls. The process of collapse is also slowed by the influence of adjacent bubbles.

Theoretical studies of the effect of the thermal conductivity of the gas on its temperature in a collapsing bubble show that a bubble whose dimensions are sufficiently large and in which the pressure of the contained gases (vapor) is low, collapses adiabatically under the influence of a sufficiently large pressure. For example, if the initial radius of the bubble R_0 is greater than 1 mm, and the initial pressure of the gas in it is 50 mm Hg, while collapse occurs at a pressure p_a = 3 at, the effect of thermal conductivity is unimportant [12].

Güth [13] has solved the problem of the collapse of a single gas-containing spherical bubble in an infinite ideal incompressible liquid at constant pressure p_a. This solution leads to the following extremal values of the pressure p*, gas temperature T*, and bubble dimensions R* at the instant of collapse:

$$p^* = p_0\left[1 + (k-1)\frac{p_a}{p_0}\right]^{\frac{k}{k-1}},$$

$$T^* = T_0\left[1 + (k-1)\frac{p_a}{p_0}\right]$$

$$R^* = R_0\left[1 + (k-1)\frac{p_a}{p_0}\right]^{\frac{1}{3(1-k)}}. \qquad (3.2)$$

Here, k is the ratio of specific heats of the gas; the subscript 0 relates to initial values of the quantities.

Thus, the effect of the ratio p_a/p_0 on the heating of the gas in the bubble is decisive. For example, at R_0 = = 1 mm, $p_a/p_0 = 10^2$, k = 1.3, and p_a = 4 at, the minimum radius R* of the bubble on collapse is about 24 μ, the

vapor temperature T* reaches 9000 °K, and the pressure p* ≈ 100 000 at.

Under actual conditions the dimensions of the bubble in the last stage of collapse will be somewhat larger, and the temperature and pressure somewhat lower than the calculated values, since part of the energy goes into compressing the liquid and overcoming viscosity forces. Nonetheless, the parameters of the vapor (gas) in the collapsed bubble should be very high, since in most liquids the saturated vapor pressure at room temperature is tens or hundreds of times lower than atmospheric pressure, and thus the ratio p_a/p_0 is large enough to give a high temperature.

β	α		p, mmHg	
	α_1	α_2	C_6H_6	$C(NO_2)_4$
3.4 : 1	1	0.11	21.5	6
3 : 1	0.9	0.096	23	5.5
4.5 : 1	1.35	0.146	17	6.5

(1 – in solution, 2 – in vapor mixture inside cavity, p – partial pressure of vapor component in cavity)

This is also confirmed, for example, by the work of Jarman and Taylor [14], who investigated the optical emission spectrum of water cavitating upon flowing through a Venturi tube. In this case the vapor temperature could be estimated from the nature of the spectrum at 5000–6000° K.

Autoignition of detonating gas in a rubber bladder collapsing in water under the action of a compression wave was noted in [15].

4. **Sensitivity of liquid explosives to cavitational initiation.** The time spent by a cavitation bubble in the compressed state τ^* is only a small fraction of the total collapse time τ. Correct to a certain dimensionless constant A (of the order of unity) this fraction, according to [13], is given by the expression

$$\frac{\tau^*}{\tau} = A\frac{p_a}{p_0}\left(\frac{R^*}{R_0}\right)^{3k+1} \approx \left(\frac{p_0}{p_a}\right)^{\frac{4}{3(k-1)}}. \qquad (4.1)$$

It is clear from (3.2) and (4.1) that although an increase in p_a/p_0 at some given value of R_0 also leads to an increase in T*, it simultaneously causes an even sharper decrease in τ^*. In this case the quantity R* also decreases. Of course, under actual conditions T* cannot rise above a certain limiting value owing to the increase in heat capacity, heat removal, and dissipation of energy that accompany a rise in temperature in the bubble.

As for the very sharp reduction (with increase in p_a/p_0) of the duration τ^* of that stage of collapse corresponding to the highest value of the temperature T* in the bubble, this is very important for an understanding of certain special characteristics of the cavitational initiation of explosion. It is possible that bubbles for which the p_a/p_0 are not too large, but ensure sufficiently high values of T* and τ^*, may be the most dangerous from the viewpoint of an explosion. Large values of τ^* favor self-sustaining chemical reactions inside the bubble itself and hot-gas ignition of the liquid explosive at the surface of the bubble.

Obviously, in the cavitational initiation of a liquid explosive the hot-gas ignition time lag t_i should not exceed τ^*, i.e.,

$$t_i \leq \tau^*. \qquad (4.2)$$

In general, the moment of ignition of the liquid explosive may be preceded by autoignition of the vapor inside the cavitation cavity (as, for example, in NG), but in certain cases (for example, in a solution of benzene in TNM) autoignition is impossible. The data in the table show that mixtures of benzene and TNM vapors above the corresponding solutions lie outside the limits of autoignition (excess oxidizer ratio $\alpha < 0.15$). The table was compiled on the assumption that the solutions obey Raoult's law.

Thus, it would seem that the ignition of a liquid explosive at the surface of a bubble by hot gases in the process determining the cavitational initiation of explosion, the autoignition of the vapor inside that bubble having only secondary importance.

Unfortunately, there has still been no theoretical analysis of the ignition of a liquid explosive by a hot spherical surface of large curvature, and it is still impossible to evaluate the critical ignition conditions.

Condition (4.2) can probably be satisfied if the initial radius of the bubble is greater than a certain critical value

$$R_0 \geqslant R_*. \qquad (4.3)$$

Thus it may be assumed that the reason for the more favorable conditions of cavitational initiation in NG when a piston with a conical tip is employed is evidently because in that case withdrawal of the piston is followed by the collapse of a fairly large cavity and condition (4.3) is satisfied.

The liquid sliding over the conical surface of the piston (as it passed through the funnel) was able to close up behind it, so that atmospheric air could not penetrate into the cavity and reduce the ration p_a/p_0. When the end face of the piston was made flat, the liquid did not have time to close up behind it, and air, entering the cavity, sharply reduced p_a/p_0 and hence T*. The dimensions of the cavitation bubbles in the middle and lower parts of the tube were probably subcritical.

It is possible that the "conical piston effect" was due to the increased viscosity of NG (36 cp); therefore, in the experiments with other explosive liquids it did not appear.

The impact of a copper plate against the bottom of a test tube containing a solution of benzene in TNM created cavitation cavities whose dimensions were apparently subcritical ($R_0 < R_*$); therefore, their collapse never produced an explosion. However, when the piston was withdrawn from the test tube, the bubbles formed were sufficiently large ($R_0 > R_*$) for an explosion to occur.

In spite of the fact that in each of these experiments fairly large bubbles were observed, an explosion was not always initiated. This may be associated both with the instability of the collapse process (breakdown of large bubbles into smaller ones) and with the nonidentical values of p_a, which varied from experiment to experiment owing to the varying intensity of hydraulic impact.

The reasons why under the conditions of our experiments a solution of heptane in TNM proved to be less sensitive and solutions of methanol in TNM and methane in liquid oxygen and the heterogeneous system solid acetylene–liquid oxygen completely insensitive to cavitational initiation are still unknown.

Nevertheless, our studies indicate that cavitation in liquid explosives is definitely a more probable explanation for the occurrence of explosions following

relatively weak impact or vibration than the collapse of bubbles of the foreign gas usually present in liquids.

Apparently, any liquid explosive is capable of exploding upon the collapse of a cavitation cavity whose dimensions are not less than the critical value. However, for insensitive liquid explosives the critical dimensions should be very large, while the probability of formation of a very large cavitation cavity is very small and, moreover, the smaller, the weaker the impact or vibration to which the liquid is subjected.

The probability of cavitational initiation should increase with increase in the amount of liquid explosive in the vessel, since in this case the fundamental frequencies of natural vibration of the liquid diminish, and longer-acting tensile forces capable of producing larger cavities become possible.

5. Propagation of explosion in cavitating NG. It was decided to investigate whether not-too-large caviation bubbles affect the velocity of propagation of explosion in liquid nitroglycerine (NG).

Instantaneous photographs (Figs. 5 and 6) show the cavitation bubbles ahead of a so-called low-velocity (1000 m/sec) explosion front in NG. In one of the experiments (see Fig. 5) a glass test tube (length 130 mm, outside diameter 15 mm, wall thickness 1.5 mm) was filled to the top with NG, the explosion of which was initiated by an impulsive electrical discharge (about 70 J of energy was released in the course of 10 μsec) through a wire immersed in the NG to a depth of 10 mm. In the photograph, taken 40 μsec after completion of the electrical discharge, the explosion front is not visible; it lies higher, outside the field of view of the lens.

In NG the speed of sound apparently does not exceed 2 km/sec, and in 40 μsec the acoustic vibrations could not have reached the bottom of the tube. Consequently, the cavitation bubbles, which are clearly discernible in the photograph at the very bottom of the tube, resulted from perturbations of the walls excited by the electrical discharge. The appearance of cavities could not be prevented even by water surrounding the test tube containing the NG (in the experiments the test tube was immersed 80 mm in a transparent vessel containing water; the diameter of the vessel was 80 mm).

The bubbles shown in the first two frames obtained by high-speed shadow motion-picture photography (Fig. 6) have the same origin. In this case the NG was poured into a test tube of rectangular cross section (10 × 15 mm) with plane-parallel lucite walls 2 mm thick. Each frame was exposed for 2.6 μsec; the interval between frames was 20 μsec. An explosion was initiated by the same electrical discharge as in the previous experiments (Fig. 5) and propagated from the top downwards at the same velocity of about 1000 m/sec. The test tube was illuminated with a flash lamp whose white image is overlapped in the photographs by the oblique dark band of the nontransparent reaction products and the silhouettes of the cavitation bubbles formed in the space between the two broad vertical bands—the thick side walls of the test tubes, also made of transparent lucite.

In the first frame the center of explosion is located in the upper left part of the test tube, where fragments of its disintegrating walls are visible. The dark oblique shadow with the uneven edges, adjacent to the image of the fragments and with its convex side turned downward and to the right, corresponds to the ignition zone. The cavitation bubbles ahead of the reaction front have dimensions of the order of 1 mm. In the second frame it is clearly visible that the ignition front is definitely not plane, and its lower edge has been displaced downward by about 2 cm. The front has already become concave, the right part lagging somewhat behind the left. In the third frame the right part of the front lags even further behind the left, in spite of the fact that there were considerably more bubbles in its path than in the path of the left part, which has moved out far ahead, and the front has again become convex.

From this it follows that a larger number of cavitation bubbles ahead of the ignition front does not increase the burning rate and has no effect on the rate of propagation of the explosion. Otherwise, the lagging part of the ignition would have moved ahead on passing through the portion of the NG containing a larger number of cavitation bubbles.

In an interesting series of experiments cavitation bubbles were created in the NG before the initiation of an explosion (by withdrawing a piston from a test tube full of NG). In this case the cavitation cavities, relatively uniformly distributed below the original position of the piston throughout the NG in the test tube, usually had a maximum size of not more than 3 mm (Fig. 7). An explosion was initiated in the cavitating NG at the top of the test tube either by means of a weak electrical discharge below the original position of the piston or upon collapse of a large cavity formed upon withdrawal of a piston with a conical tip. In both cases the bubbles created upon initiation of an explosion by the vibration of the walls of the test tube, as in the experiments illustrated in Fig. 5, were added to the cavitation bubbles already existing in the NG.

The measurements show that in the presence of such artificially created cavitation the explosion in the NG again always propagated at the same low velocity of approximately 1000 m/sec.

Special experiments revealed that in time-resolved photographs of the motion of the detonation front in a solution of benzene in TNM it is likewise impossible to observe the slightest changes in the inclination of the image of the trace of the front when it passes from a liquid not containing cavitation cavities into a region where small bubbles are present in large numbers.

Thus, the experiments confirmed the conclusions of [16] regarding the occurrence of cavitation in NG in the presence of a low-velocity detonation due to perturbations propagating through the walls of the vessel. At the same time, the results of the experiments described above indicate that the process of collapse of the cavitation cavities occurring in NG ahead of an explosion front traveling at about 1000 m/sec has no positive effect on the initiation of a reaction in the front.

Under other conditions the collapse of cavitation cavities probably promotes the propagation of an explosion. For example, in [17] it was established that under the action of a shock wave of 86 kbar, solid particles of tungsten or plastics immersed in nitromethane initiate an explosion equally as well as gas bubbles. In this case the shock wave itself stongly heated the nitromethane, and initiation of an explosion only required a small amount of additional heating of the liquid, which could be obtained both from the reflection of the shock wave from solid particles and from the collapse of bubbles.

In the latter case the additional rise in the temperature of the liquid nitromethane near a bubble was due not only to heating of the gas in the bubble, but also to shock compression of the liquid in the shock wave which always accompanies the rapid collapse of a bubble.

It is interesting to note that in these experiments also, bubbles that did not have a sufficiently large initial diameter (0.5 mm or less) were unable to initiate an explosion in nitromethane.

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