HOT LIQUID DISPERSION DURING DISINTEGRATION OF THE SHELL

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Modern technological devices sometimes use processes where the liquid pressure drops rapidly to a value below the saturated vapor pressure. In particular, one type of such a rapid, essentially transient, process involves the depressurization of a macroscopic volume of a hot liquid when the vessel bursts. The mathematical description of the burst is difficult due to the presence of phase transition.

The problem considered in [1, 2] involved depressurization of one vessel wall, which actually reduced the process to the outflow from a tube, i.e., the case of one-dimensional geometry.

We have photographed the dispersion of hot Freon-113 caused by disintegration of a glass vial. We propose to investigate the effect of the liquid's initial temperature on the dispersion rate of the burst cloud in the range of parameters of state where intensive, spontaneous nucleation in a metastable liquid may occur [3].

The experimental device consists of a cubic metal chamber 50 cm on a side. The chamber has two windows, one on top and one in its side. The top window is used for flash illumination by a lamp, and the side window is used for photographing. Light pulses with a duration of approximately 1 μsec are produced by means of an air spark gap.

The operating medium is Freon-113, which is an incombustible, nontoxic compound. The low values of the critical parameters ($T_c = 487.2$ K, $p_c = 3.41$ MPa) make it possible to use annealed-glass vials with a wall thickness of 0.5 mm. The vials are spherical and have a diameter of 2.5 cm. The filling (approximately 4 g) maintains the liquid—vapor interface roughly at the middle of the vial at any temperature in the range from the room temperature to the critical one. The vial and the entire chamber volume are heated by heaters located at the chamber walls. The temperature is measured by means of a copper—Constantan thermocouple, which is in thermal contact with the vial. The initial temperature is in the range from 388 K ($\approx 0.8\,T_c$) to 487 K ($\approx T_c$). Vial disintegration is initiated by a spring-loaded striker. A fine copper wire with a diameter of 0.03 mm, pasted to the vial, serves as the data unit indicating the start of disintegration. We used a flash lag in the 0-1 msec range following the instant of wire rupture.

Series of photographs of identical specimens were obtained with different time lags for each of the temperatures used. Figure 1a-e, shows the characteristic photographs of the burst cloud for the reduced initial temperatures $\tau = T_0/T_c = 0.95, 0.92, 0.90, 0.85, 0.80$ and the lag times t = 50, 100, 200 μsec. The boundary of the expanding vapor—liquid mixture is clearly defined in the photographs. It is quite evident that the rate of cloud dispersion increases with the initial temperature T_0.

The parameter to be measured is the diameter of the burst cloud D, i.e., the distance between the extreme visible boundaries of the vapor—liquid mixture that are farthest apart. Figure 2 shows the relative increase in the burst cloud volume $\varphi = (D/D_0)^3 - 1$ as a function of the time (D_0 is the vial diameter) for $\tau = 0.95, 0.92, 0.90, 0.85, 0.80$ (curves 1-5).

The time measurement starts following the spreading of cracks through the glass and the subsequent rupture of the wire. Initially, inertia does not allow the vial fragments to free the liquid surface instantaneously. We can calculate the time in which the fragments will reach a spherical surface whose area is twice as large as the area of the initial vial, assuming that they move with equal acceleration. For $\tau = 0.95$ ($\Delta p = 2.45$ MPa), this time is equal to 83 μsec. According to experimental data, the boundary of the burst cloud expands to this distance in approximately 30 μsec. A time which is fairly close to the experimental value (35 μsec) is obtained in calculating equal-acceleration motion of a Freon-113 drop

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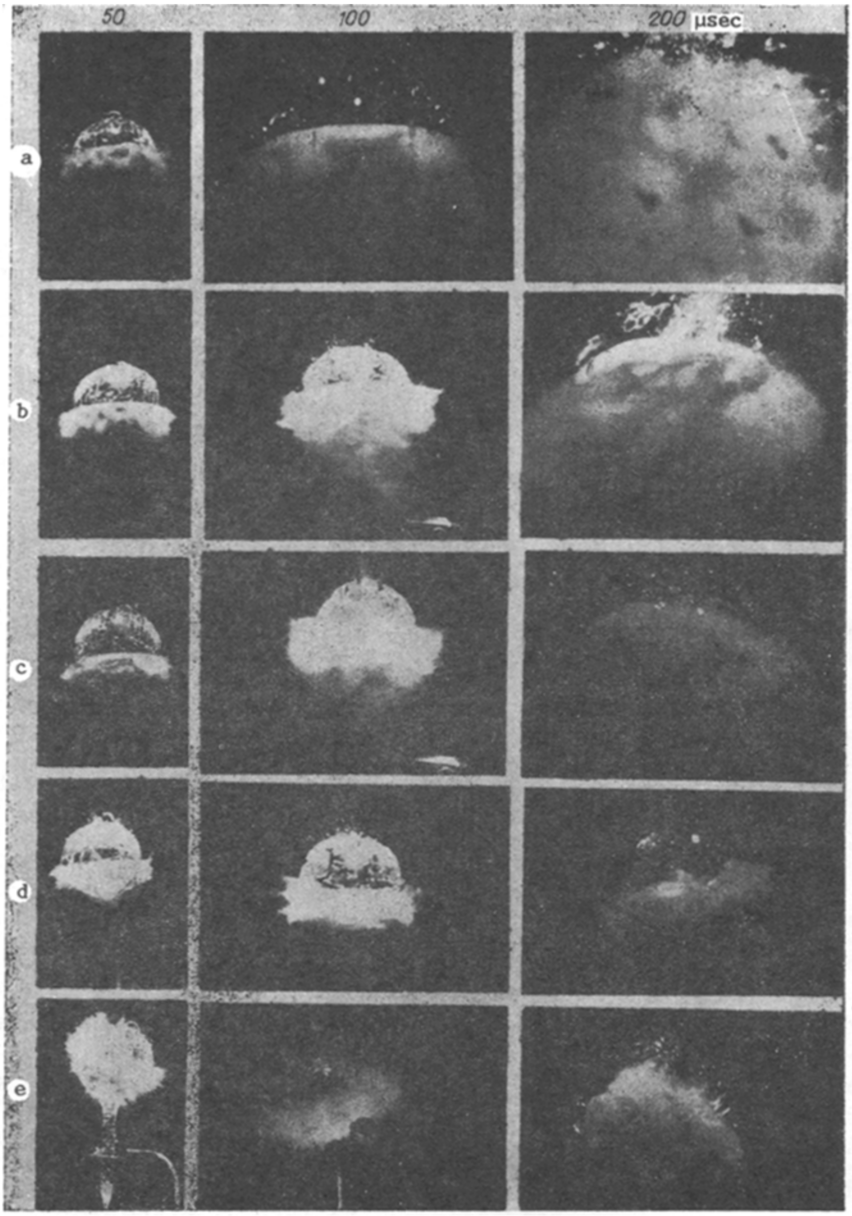

Fig. 1

under the action of the same pressure drop. It follows from these estimates that the presence of glass fragments does not hinder the expansion of the vapor—liquid cloud even at the initial stage of the dispersion process.

Immediately upon depressurization of the vial, a low-pressure wave propagates in the liquid during a period of approximately 20 μsec. Behind the low-pressure wave, the liquid boils up and the vapor—liquid mixture expands; the rate at which the relative volume increases rises with an increase in the initial temperature.

We distinguish between two vaporization stages during the hot liquid depressurization: 1) development and growth of vapor bubbles in the main part of the liquid and evaporation from the liquid's external surface; 2) vaporization of the multitude of small droplets, produced by the disintegration of the initially homogeneous mass. The formation of embryonic bubbles within the volume is essential at the initial stage of the process while the volume share of vapor is $\alpha < 0.5$, i.e., while there is a large mass of liquid. The degree of dispersity of the medium during further expansion of the cloud depends on the nucleation intensity. We can assume that the larger the number of bubbles formed in the main mass of the liquid at the initial stage, the larger the interface surface and the faster the cloud expansion for $\alpha > 0.5$.

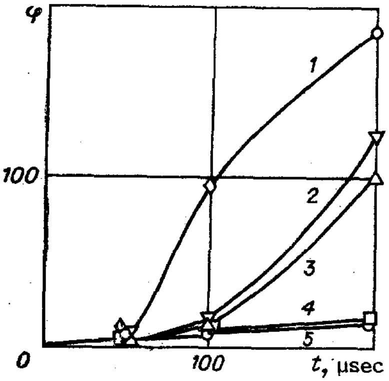

Fig. 2

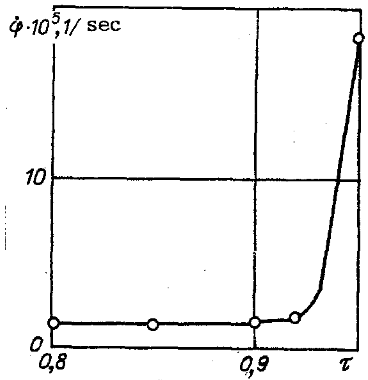

Fig. 3

TABLE 1

τ	$\dot{R}$,m/sec	p_0,MPa	a, m/sec
0,80	150	0,63	396
0,85	165	1,06	408
0,90	155	1,60	420
0,92	175	1,86	424
0,95	685	2,45	431

Figure 3 shows the vaporization rate as a function of the temperature. The vaporization rate was estimated with respect to two points, at t_1 = 50 μsec and t_2 = 100 μsec: $\dot{\varphi} = (\varphi_{100} - \varphi_{50})/5 \cdot 10^{-5}$ sec^{-1} (φ_{50} and φ_{100} are the relative volume increments at 50 and 100 μsec, respectively). Figure 3 clearly shows the sharp increase in the vaporization rate for $\tau > 0.9$.

Table 1 provides the absolute velocity of the burst cloud boundary $\dot{R}$ and the initial pressure inside the vial p_0 in relation to the reduced temperature. The velocity of the cloud boundary was also determined with respect to two points, t_1 = 50 μsec and t_2 = 100 μsec. The velocity of sound in air at the initial vial temperature is also given for comparison. It is evident from Table 1 that $\dot{R}$ increases sharply for $\tau > 0.9$.

For $\tau > 0.9$, the pressure in the body of the liquid drops after depressurization to values close to the feasible overheating curve, when the mechanism of homogeneous fluctuation nucleation [3] becomes operative. This ensures the appearance of a large number of spontaneously developing vapor bubbles in the liquid volume. The boiling-up occurs rather rapidly – in tens of microseconds. The presence of the fluctuation mechanism of nucleation may in fact ensure the explosive character of boiling-up that is observed in experiments.

Thus, in a detailed description of the depressurization of a hot ($\tau > 0.9$) liquid, it is necessary to take into account, especially in the initial stage of the process, the formation of vapor nuclei within the main part of the liquid. The theory of homogeneous fluctuation nucleation can be used for this purpose.

LITERATURE CITED

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