FIRST OSCILLATION SHOCK INDUCED OXYGEN BUBBLE DYNAMICS AND IGNITION INSIDE A CLUSTER OF A MONODISPERSED BUBBLY ORGANIC LIQUID

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The basis of the bubble explosion mechanism is the well known mechanism of transformation of pressure waves in inert bubble media: Energy from the incident shock wave is absorbed from the bubble. This energy is consumed for an increase in internal gas energy, namely, the temperature of the compressing bubble and is then re-radiated by the bubble during pulsation. Apparently, when attaining the ignition temperature the bubble explodes. Investigations of bubble explosions in organic liquids have a special interest since the liquid can play an active role during the bubble ignition process. In this work investigations on the first oscillation shock induced dynamics and ignition of oxygen bubbles inside liquid cyclohexane are presented.

The system investigated in this work was consisted of pure cyclohexane containing oxygen bubbles inside a cylindrical autoclave of 100 mm inner diameter and 1070 mm length. The surface of the liquid was situated 350 mm above the bottom of the autoclave. A shock wave in the liquid was generated by a gas detonation of an explosive mixture above the liquid. The pressure peak of the incident shock wave in the liquid varied in the range between 50 bar to 70 bar.

The pressure data were recorded with a time resolution of 1 μs. They were smoothed with a running average of 20 points, to reduce the influence of the natural oscillations of the pressure transducers. Averaging over 20 points corresponds to exactly 3 oscillation periods of the transducers.

The interaction of the bubbly liquid with the incident shock wave was observed with the help of digital high speed framing photography. The bubbles were typically of non spherical shape. The bubbles' diameter in the monodispersed medium was varied in the range of 2.4 mm to 6.7 mm. The equivalent diameter was defined by: $d_e = (ab^2)^{1/3}$, where a and b are the minor and major axes of the bubble, respectively. All experiments were performed at room temperature (20 ^oC - 25 ^oC), and initial pressure 1 bar.

The following stages of shock induced bubble behaviour were observed. After some time period the bubble starts to shrink. During the compression a jet forms, which penetrates the bubble (e.g. see figure 1, 22 ms).

The main reason for this jet formation is assumed to be the inhomogeneous pressure field in the liquid near the bubble, as well as surface instabilities and the non symmetrical bubble form. While it seems that bubbles which are very near of other bubbles tend to form the jet earlier, a certain pattern on the creation of the jet formation was not revealed by these investigations. Generally the jet was formed when the bubble radius, r, reached the range: $0.5 \le r/r_0 \le 0.9$, (where r_0 is the initial bubble radius). As a result of the jet penetration through the bubble, mass and heat transfer phenomena are expected to be intensified, eventually influencing the explosion behavior of the oxygen bubbles during the next behavior stage.

After the jet formation, the bubble compression continues. For an inert bubble two possible behaviors were observed. Either the bubble was broken up into two parts, or the bubble remained unbroken and reached a minimum diameter which was followed by an expansion phase. This minimum typically reached a value between $0.2 \le r/r_0 \le 0.3$, but higher values were observed too. During the compression phase of oxygen bubbles, ignition was also observed (e.g. see figure 1, 33 ms). This ignition took place always when the bubble remained unbroken. It took place at a compression level of $0.2 \leq r/r_0 \leq 0.6$. The measured ignition delays (time from the incident shock wave impact to bubble ignition), t_{ign}, were in the range from 15 ms to 60 ms. A connection between the length of the ignition delay time and the bubble radius was found, as expected. Between two bubbles with significant difference in size, the smaller one has the shorter ignition delay. The bubble explosion is followed by light and a strong spherical shock wave emission and results into a bubble expansion phase (e.g. see figure 1, bubble No.2: 35 ms - 40 ms). The duration of this light emission was between 1 ms and 6 ms, and typically about 4 ms. The expansion phase ends when a maximum bubble size is reached, which is limited by the pressure level inside the liquid at that time. It was found that bubbles which are very near to each other do not collide during the compression phase, such collision can though occur during the expansion phase that follows. An example of shock induced bubble dynamics is shown in figure 2. In table 1 a summary of the shock induced behavior of the oxygen bubbles of figure 1 is presented.

It should be noted also that not all oxygen bubbles exploded, even though they were of the same diameter, compared to others that exploded, during the same experiment. This indicates the highly dynamic nature of the parameters that influence the bubble ignition processes.

An other point of interest is that shock waves emitted by exploding bubbles were able to trigger bubble ignition of nearby compressing bubbles. An example of this behavior can be seen in figure 1. The bubble No. 2 ignition was initiated by the overlapping of two shock waves from nearby bubble explosions (figure 1, 35 ms). The shock wave from this explosion ignited the Bubble No. 4 (figure 1, 40 ms). The fact that bubble explosions can ignite nearby compressing bubbles indicates that an automatic process of sychronisation of bubble explosions is possible. This behavior could help us to understand better the exact mechanism of self-sustaining waves inside bubbly media.

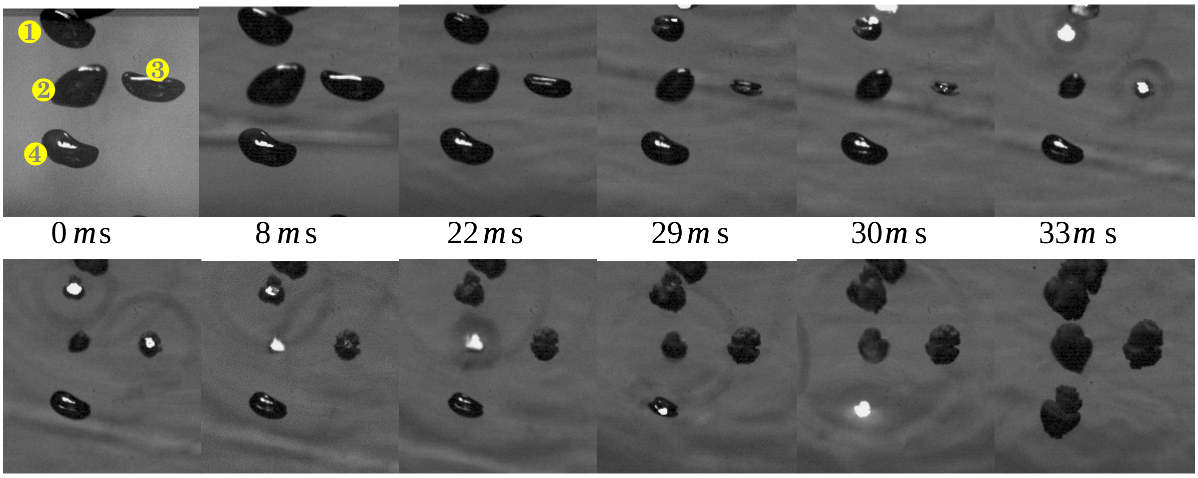

Figure 1

Shock induced dynamics and ignition of oxygen bubbles: Jet penetration through the bubble No. 3 (22 ms). Initiation of ignition in the bubble No. 3 (30 ms). Ignitions initiated by other bubble explosions (35 ms and 38 ms). Time zero corresponds to the moment when the shock wave enters the observation window. The pressure in the liquid is presented in figure 3.

Bubble No.	$2 \cdot r_0$ [mm]	t_{inj} [ms]	r/r_0	t_{ign} [ms]	r/r_0	Δt_l [ms]
1	3.7	15	0.90	32	0.33	4
2	4.1	22	0.77	32	0.27	2
3	3.6	10	0.82	27	0.27	4
4	3.6	23	0.80	31	0.47	5

Table 1

Experimental measurements from the bubbles in figure 1. r_0: initial bubble radius; t_{inj}: moment of jet formation; t_{ign}: ignition delay; Δt_l: duration of light emission during the explosion. Time zero for each bubble corresponds to the moment of the incident shock wave impact on it.

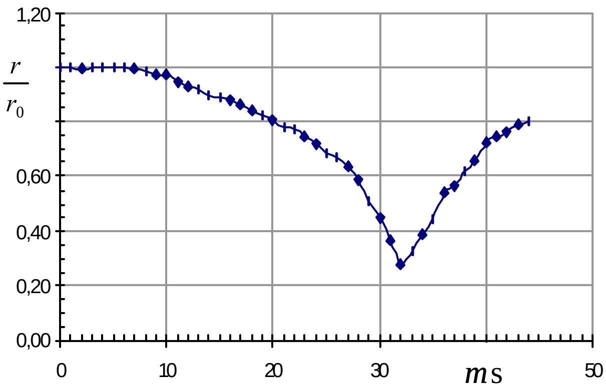

Figure 2

Shock induced dynamics of the bubble No. 2 in figure 1. Time zero corresponds to the moment of shock wave impact.

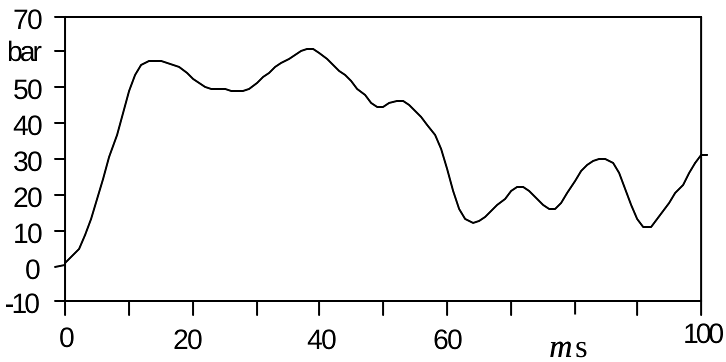

Figure 3

Pressure in the liquid during the first 100 ms after the beginning of the incident shock wave, for the experiment shown in figure 1.

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