EPJ Web of Conferences **269**, 01054 (2022) https://doi.org/10.1051/epjconf/202226901054
EFM 2019

Evolution and implosion of cavitation bubbles towards solid surface

Petr Schovanec[1,*], *Darina* Jasikova[1], *Michal* Kotek[1], and *Vaclav* Kopecky[1]

[1]Department of Physical Measurement, Technical University of Liberec, The Institute for Nanomaterials, Advanced Technology and Innovation, Studentska 1402/2, Liberec 461 17, Czech Republic

Abstract. Cavitation bubbles generated via laser-induced breakdown are investigated experimentally. The present work focuses on the direction of the first bubble collapse near a solid surface in distilled water. The solid surface is placed first to the right side in a cuvette filled with distilled water and then placed to the top of the cuvette. In this experiment, it is observed in which direction the cavitation bubble collapses. The cavitation bubble is visualized by a high-speed camera of frequency 68kHz.

1 Introduction

One of the earliest articles that deal of focused laser light in liquids was published in the 1960s by Askar'yan [1]. Then the study of cavitation bubble dynamics generation by laser-induced breakdown was emphasized by Lauterborn [2]. The dependence of the bubble radius and the duration of the laser pulse energy was investigated by Teslenko [3]. In the following years up to now, a great deal of research and application of laser-induced breakdown has been emerging and expanding. Because cavitation belongs not only to industrial applications, but also to biomedical fields such as medicine, biology or pharmacy. The cavitation phenomenon has great potential e.g. in drug delivery systems or cell walls disintegrations.

Cavitation can be defined as a set of effects associated with the formation, activity, and collapse of macroscopic bubbles in a fluid. In nature and in real applications, cavitation bubbles usually form a cloud, yet the bubbles do not separate. Bubbles create structures that work together, but the essential elements of these structures are the individual bubbles [4].

We still cannot produce one controllable bubble according to the cavitation definition, by decreasing the pressure in the volume of the liquid even though the current state of technology is at a very high level [5]. Most methods, such as sparks or laser generated bubbles, are based on evaporating a small volume of liquid, that is closer to the boiling. In our case we use the laser-induced breakdown (LIB) technique, where there is still a lack of information in the experimental part of the bubble cavity investigation [6].

Previously, cavitation research has focused primarily on the behavior of bubbles near solid or flexible boundaries and the behavior of bubbles in various liquids [6, 7]. This present work follows the investigation the collapse of a cavitation bubble towards a solid surface located from different directions.

2 Experimental setup

The experiment part leans against the previous work done by Jasikova et al [6]. It is the calculation of the ideal cavitation bubble process and based on the energy losses in the system. The experiment contains laser, a camera, a timer box and a continuous light. The laser serves to generate plasma, followed by a shock wave and cavitation bubble in the liquid using the laser-induced breakdown the method. The continuous light is used to illuminate a cuvette for camera to take photos. The timer box is used to synchronize the time between the laser and the camera.

2.1 Laser Induced Breakdown

Laser-induced breakdown is a method in which laser light in a liquid is focused using appropriately designed optics. This method of LIB in aqueous media and its collateral effects has been described in detail by Kennedy [8]. In addition is followed by Vogel's work [9] on energy distribution during the growth and collapse of laser induced bubble.

In this work we used high power laser with a short pulse (t = 10ns) and wavelength (λ = 532nm). A 10ns short laser pulse was generated using a Q-switched Nd: YAG Quantel EverGreen PIV pulse laser. This laser worked with one cavity to generate a single shot. The camera running in the trigger mode with the laser was synchronized by the Q-switch signal.

To correlate the input laser energy with the bubble size generated by our optical adjustment, we performed a set of calibration and size measurements. The energy of the

*e-mail: petr.schovanec@tul.cz

laser beam was adjusted and measured by the pyroelectric energy sensor Ophir.

Due the losses in the optical path on each of the optical elements, comparable to this one, we had to increase the energy level that enters the entire system. The set laser output energy is taken into account in relation to the bubble diameter. The energies needed to generate the bubbles are shown in Figure 1.

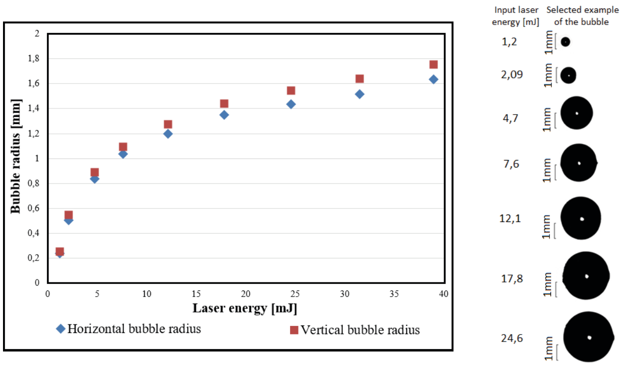

Fig. 1. The graph of maximal bubble diameter.

2.2 Optical setup

Optical setup is based on the direct optical way described by Brujan [10] and the follow-up work by Jasikova et al [7]. The LIB has been set up as an optical direct mode and is shown in Figure 2. The laser beam output diameter was 5mm with Gaussian intensity characteristics. In this arrangement was followed by a concave lens fs = 30mm and two planar convex lenses fs = 75mm and fs = 50mm of 1 inch in diameter. Laser point - probe with diameter <0.1mm was created by focusing the laser beam.

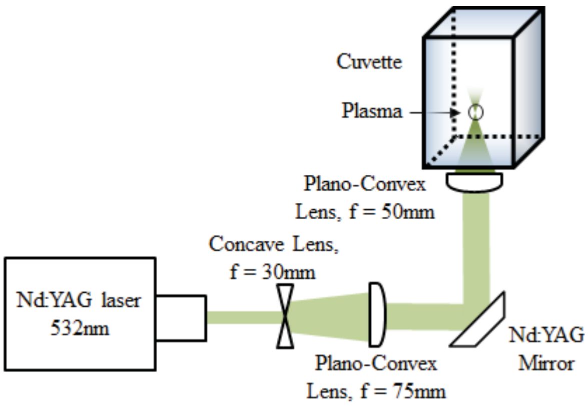

Fig. 2. Optical setup.

2.3 Visualization setup

Visualization setup follow the work [5, 6]. We used here shadowgraphy setup for the bubble visualization. This setup consists of continuous LED matrix daylight lamp Veritas, MiniConstellation 120 - 5000K of illuminance 92klux in 0.5m, set with optical diffuse filter. Opposite to the light source was placed high speed CMOS camera SpeedSense. This camera is working on frequency 68kHz with resolution of (256 x 256)px or lower frequency with higher resolution up to (1280 x 800)px, and the dynamic range 12bit.

The exposure time for the camera was set to 1μs and subpixel resolution was 20μm. The camera was mounted with optical lens system INFINIPROBE^{TM} TS-160 universal macro/micro imaging system that enables 4x, and 16x magnification. The camera was mounted with edge pass and long pass filter cut-on wavelength 550nm low pass optical filter to reduce the backward laser flashes to the camera and also to eliminate the flash generated while plasmatic breakdown. Visualization setup is shown in Figure 3.

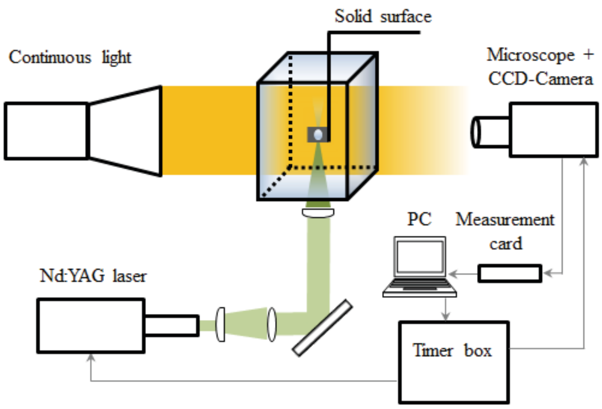

Fig. 3. Experimental setup the visualization system for shadow graphics.

3 Results

Plasma is generated at the location of the laser energy concentration and the plasma is visible for emission. At this plasma point in the liquid, the pressure rises to 10^3bar and the temperature to 10^3K. This leads to plasma expansion at supersonic velocities, and is followed by a cavitation bubble effect. For Figure 4 at time $t_0 = 0\mu s$, it is important that the laser light comes from the bottom side in the pictures.

Figure 4 represents a selected part of a series of images show the formation, evolution, implosion, and behavior of bubbles. In the first column of Figure 4, the solid surface is placed from the right side and in the second column is placed from the up side.

Bubble was generated with the laser energy of 4mJ and 3mJ. The first frames in the time of t_0 show the position of the optical breakdown. The images in the time of t_1 show the enlargement of the cavitation bubble that is very close to the maximum of its diameter.

In the other images in the time of t_2, the direction of collapse of the first phase of the bubble life is seen. With the collapse of the bubble at the second stage of its lifetime in the times of t_3 to t_6, the collapse is attracted by the solid surface in its vicinity. Even when the solid surface is applied from the top, the bubble collapse is pointing upward as seen in the time t_3.

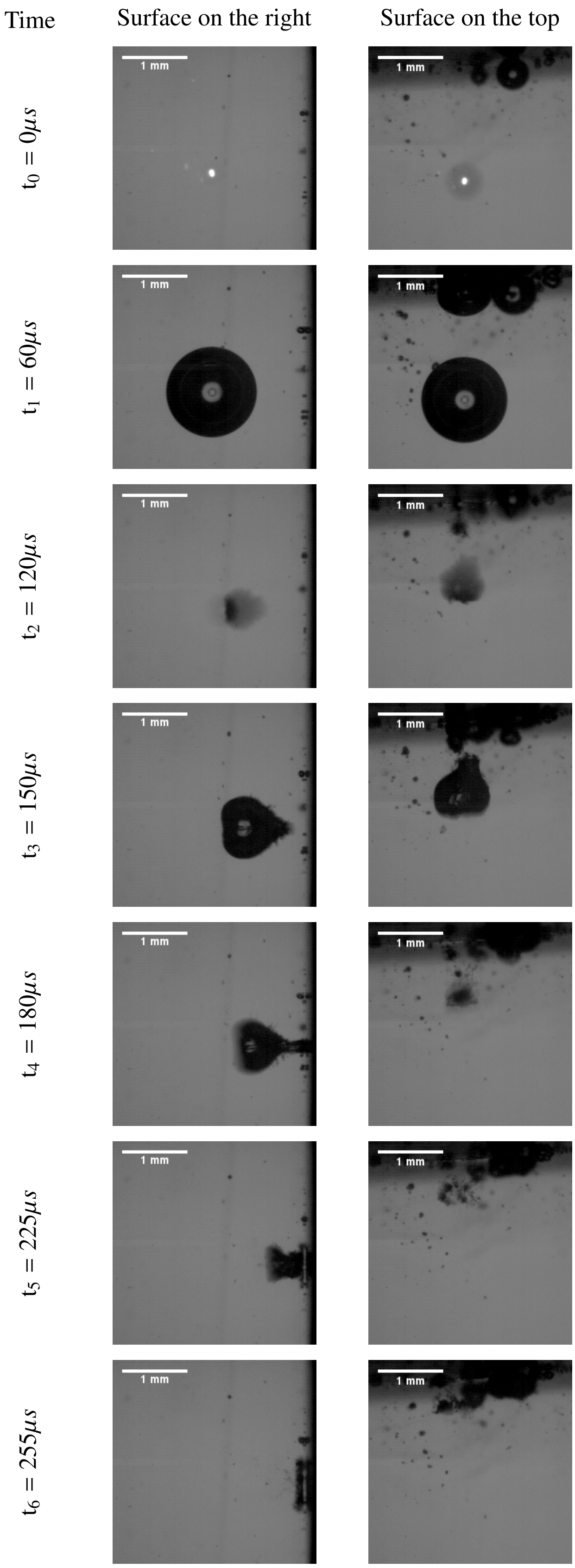

Fig. 4. Evolution of bubbles towards solid surface.

Figure 5 represents a selected part of a series of images show the implosion of bubbles. In the first column of Figure 5, the solid surface is placed from the right side and in the second column is placed from the up side. For the images located in the left column of Figure 5, laser energy of 3mJ and 10mJ was used for the images in the right column. That is reason why the time of bubble implosion was different. The frames at time t_0 show the direction of implosion of the bubble generated.

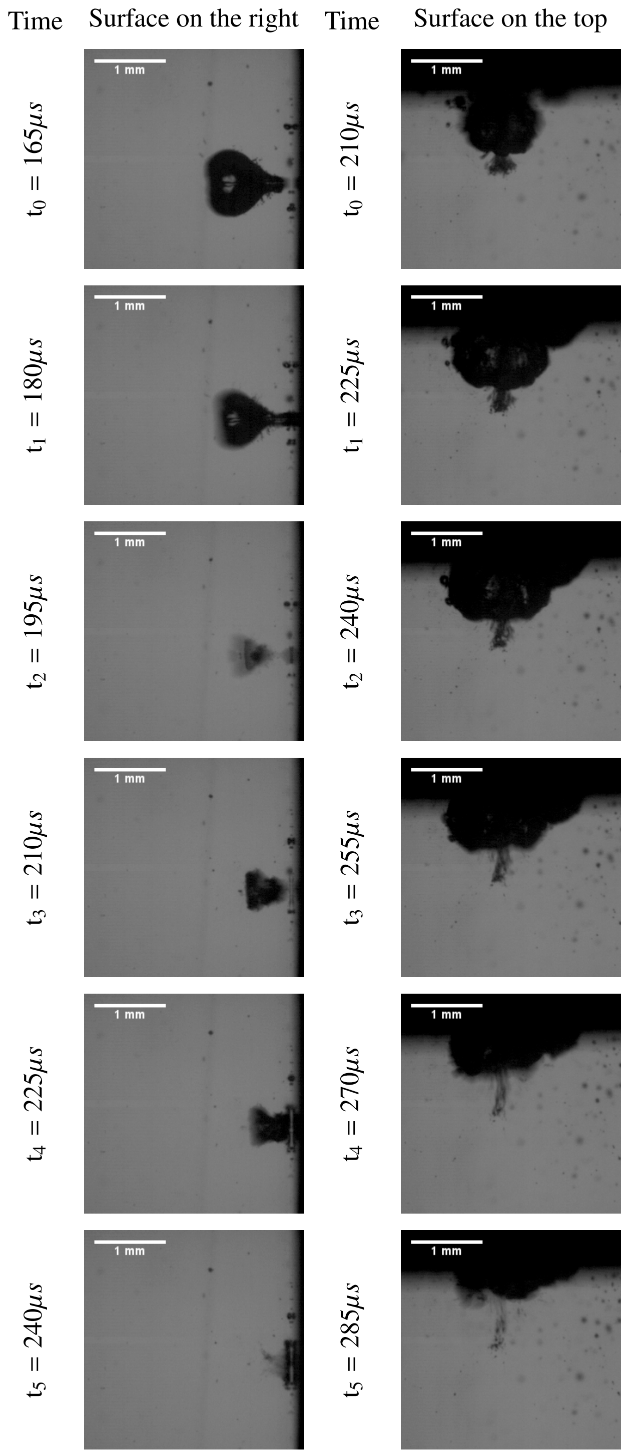

Fig. 5. Detail on micro-jet creation through collapsing cavitation bubble.

This implosion is directed towards a solid surface. In the frames at time t_1 - t_5, the effect of the bubble implosion on a solid surface is seen. Primary demonstration of micro-jet formation through the collapse of cavitation bubbles. The micro-jet was well captured specifically at time t_0 in Figure 5.It is therefore evident from these series of images that the implosion of the bubble is not directed like gravitational force, but towards a solid surface, no matter where it is located.

4 Conclusion

When studying the cavitation process, visualization of cavitation bubbles is a very important and useful tool. We visualized the limits of the bubbles in their growth, size and direction of collapse.

The plasma expansion is followed by a shock wave and during this sequence the liquid evaporates and the cavitation bubble grows. This bubble is filled with steam. The bubble collapse occurs during the second phase of bubble lifespan. The collapse is caused by a decrease in internal pressure and cooling, which is influenced by the external environment. Bubble collapse is attracted towards a solid surface near it.

Acknowledgements.

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic and the European Union - European Structural and Investment Funds in the frames of Operational Programme Research, Development and Education - project Hybrid Materials for Hierarchical Structures (HyHi, Reg. No. CZ.02.1.01/0.0/0.0/16_019/0000843), and the SGS project no. 21338/115 of the Technical University of Liberec.

References

1. Askar'yan, G.A., Prokhorov, A.M., Chanturiya, I.F., Shipulo, G.P., Sov. Phys. - JETP **17**, 1463 (1963)
2. Lauterborn, W., Applied Physics Letters **21**, 27 (1972)
3. Teslenko, V.S., Soviet Journal of Quantum Electronics **7**, 981 (1977)
4. Schovanec, P., Garen, W., Koch, S., Neu, W., Dancova, P., Jasikova, D., Kotek, M., Kopecky, V., ACC JOURNAL **25**, 58 (2019)
5. Jasikova, D., Schovanec, P., Kotek, M., Muller, M., Kopecky, V., Proceedings of SPIE **10151**, 154 (2016)
6. Jasikova, D., Schovanec, P., Kotek, M., Muller, M., Kopecky, V., EPJ Web Conf. **143**, 02044 (2017)
7. Jasikova, D., Schovanec, P., Kotek, M., Kopecky, V., EPJ Web Conf. **180**, 02038 (2018)
8. Kennedy, P.K., Hammer, D.X., Rockwell, B.A., Progress in Quantum Electronics **21**, 155 (1997)
9. Vogel, A., et. al, Applied Physics B **68**, 271 (1999)
10. Brujan, E.A., Nahen, K., Schmidt, P., Vogel, A., J Fluid Mech **433**, 251 (2001)