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LARGE CAVITY DETAILS FOR SUPERHEATED LIQUIDS

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Abstract. *It is well know that pure substances (or almost pure) can be maintained in the liquid phase for temperatures much higher than those of the liquid-vapor phase change. In these superheated cases, it is necessary to startup the phase change through some adequate nucleation mechanism, generating a very fast sequence of phenomena. In the present study, a confined liquid (distilled water) was subjected to an adequate situation of pressure and temperature that allowed forming macro cavities, and because of the sudden expansion, generated a piston-like movement for the liquid dislocating. First tests were performed, in which the generation and collapse of cavities with lengths of about 25 cm were observed. The experimental system allows a good approximation to a one-dimensional movement of the volume of water, but also allows to observe intriguing geometrical patterns forming at the upper surface of this volume. The results show that the sudden expansions, with high accelerations and decelerations, impose the formation of local "jets", which can only be observed in detail using high-speed cameras. The descriptions presented here show the high potential of studies in which controlled macro-scale cavities are generated following the procedures presented here.*

Keywords: *Macro cavitation, Bubble dynamics, Metastable state.*

1. INTRODUCTION

The cavitation phenomenon may be defined as the formation of vapor cavities in liquids, together with its evolution and collapse. This phenomenon has been studied by the scientific community along the twentieth century, and many aspects of the process were described and quantified. Cavitation is commonly associated with its negative consequences, like erosion, losses and noise in pipes, turbines and other mechanical devices, as described in Falvey (1990). In the last decade a change of point of view conduced to a more favorable evaluation of cavitation events, and a lot of positive aspects associated to cavitation can now be found in the literature. A field where it had a significant development is, for example, medicine. Brujan (2011) describes the use of cavitation for ultrasonic and cell surgery, where the formation of cavities is induced by a laser or a sound pulse, being the mechanism for ultrasound-assisted gene transfer and drug delivery. Another application is in the treatment of water, as a disinfectant. As shown by several authors (Azuma, *et al*., 2007, and Assis, *et al*., 2008), the high-pressure waves and the high-velocity microjets generated by the implosion of the bubbles may eliminate most of the microorganisms present in wastewaters. Also in the nature (wild life) we may find examples of animals that use cavitation as a defensive/offensive mechanism, like the snapping shrimp, which uses cavitation bubbles to stun their prey (Patek and Caldwell, 2005). However most of the studies and applications involve only micro cavities, with diameters of the order of few millimeters.

Only recently some innovative techniques were presented in the sense of studying controlled macro cavities. Schulz, *et al*., (2012) show in his original study, which is probably pioneer in this subject, the generation of cavities with diameters of the order of 10^{-1} m, producing forces of the order of 476 N and moving the container in which they were generated.

This paper is concerned to show features of macro cavitation that are observed in systems similar to those used by Schulz, *et al*., (2012), discussing the factors that can interfere in the phenomenon and similarities whit the dynamics of micro cavities.

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2. EXPERIMENTAL ARRENGEMENTS

The experiments conducted in the present study were performed using devices specially constructed to generate and to allow the observation of details of macro-scale cavities. Cavitation is a quick nucleation phenomenon, which is generally observed in small-scale controlled experiments. This study uses the technique presented by Schulz et al. (2012), but improving the geometry of the container, allowing observing details of the phenomenon without curvature effects, present in the former experiments.

2.1 Water container

Considering the use of new containers, the general constructive aspects are described here, in order to allow the reproduction of the experiments. The testes were made in a glass container filled with water (in liquid and gaseous phases) with the dimensions shown in Fig. 1.

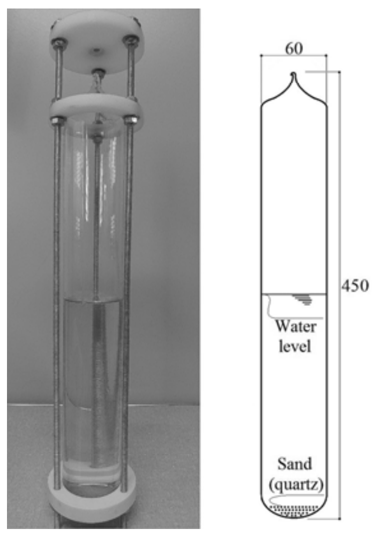

Figure 1. Water container. Dimensions in millimeters.

As can be seen, this geometrical arrangement shows a preponderant vertical dimension, which also induces a preponderant vertical movement of the water. Although this container was build based on the indications of Schulz, *et al*., (2012), the present shape showed to be much more adequate to obtain movements closer to the one-dimensional case.

The tubes of the containers were made of Pyrex glass, having thickness of 1,5 mm, diameter of 60 mm, and length of 450 mm. In the upper part a capillary tube was fixed, having a length of 60 mm. The container was subjected to an annealing process at a temperature of 520º C for a period of 24 h, eliminating thermal stresses.

2.2 Holder

The former experiments (Schulz, *et al*., 2012) showed that the forces involved in such cavitation events are high, and a solid holder must be provided in order to allow adequate measurements. The structure of the holder, however, is composed by a set of components that guarantee the integrity of the container during the experiment. These components are described in the sequence.

2.2.1 Bracket

The experimental device was fixed to a concrete pillar using a bracket built on iron, which was screwed on the pillar. The charge cell for the measurements of force was fixed on this bracket. The container was then fixed to the charge cell, and the nucleation events were forced, in order to make the observations and the measurements.

The bracket and the charge cell are shown in Fig. 2.

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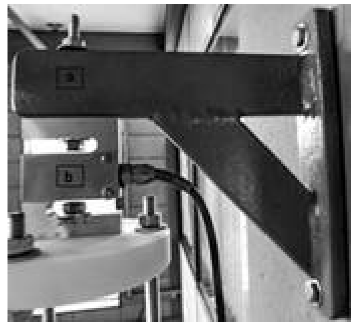

Figure 2. Bracket (a) and charge cell (b).

2.2.2 PVC plates and washers

In order to hold the glass tube of the container and to allow fixing it at the charge cell, PVC plates were prepared as shown in Fig. 3, being then connected together with the water container using steel rods, as shown in Fig. 1. Two plates were shaped as washers, so that they could adequately dovetail on the bottom and upper parts of the container. A third circular plate was used to fix this structure at the charge cell. Fig. 3 shows the plate and washers prepared for the experiments.

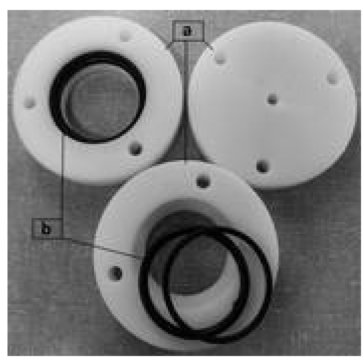

Figure 3. PVC plate and washers (a) and O-rings (b).

2.2.3 O-rings

Fig. 3 also shows the O-rings used to absorb the “impact” between the PVC components and the glass of the water container, avoiding the breakage of the glass. Two O-rings were placed in each of the PVC washers, perfectly fitting eventual spaces and protecting the container.

2.3 Preparation of the experiment

2.3.1 The internal liquid

An amount of 15,55 g of sand was placed inside the container. The sand avoids the formation of strong thermal convections when heating the bottom of the container, so that the heated water stays at the bottom while storing the energy needed to the nucleation. The container was then totally filled with distilled water. The water was boiled using a burner until a water column of only 20 cm remained in the container. The time needed to evaporate the excess of water was about three hours. With the water still boiling, the capillary tube was melted with a torch and closed. The system was then allowed to cool at the environment temperature, until the thermal equilibrium with the environment was reached.

2.3.2 Heat generation for the nucleation

The nucleation was forced using a common lighter, kept at a distance of the bottom of the container such that the yellow flame was maintained in contact with the glass (instead of the blue flame). This procedure was followed to prevent the formation of thermal stresses within the glass.

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Nucleation was always formed close to the bottom of the container, which was guaranteed by the sand used to store the thermal energy.

3. MOVEMENT VISUALIZATION

For the visualization of the experiments the holder, the container, and a high velocity camera attached to a tripod were used. The camera was adjusted to 320 frames per second, and adequate conditions of light and position were chosen to obtain the pictures presented here. The movies obtained during the cavitation events were studied in slow motion and the relevant frames were then selected and edited.

4. EXPERIMENTAL VISUAL RESULTS

After some seconds of heating, a nucleation occurs in the water within the sand at the bottom of the container, which then suddenly expands, resulting in an interesting and very attractive event (somewhat resembling an explosive reaction).

The initial nucleation bubble formed through evaporation quickly expands until the diameter of the tube is reached, after which an almost one-dimensional vertical growing takes place. The expansion impels the water column upwards until either it collides with the top of the container or the bubble attains its maximum expansion. This creates a piston like movement of the water, as shown in Fig. 4. It is interesting to note that, different from Schulz, *et al.*, (2012) in this container it was not possible to observe a torus like cavity. In pictures “g” to “i” of Fig. 4 it is possible to observe the breakage of the central part of the ceiling, with a kind of “central jet”, but no torus like cavity is formed. In Fig. 4j the central jet already appears dispersed.

The total time of the experiment shown in figure 4 was 156,2 ms.

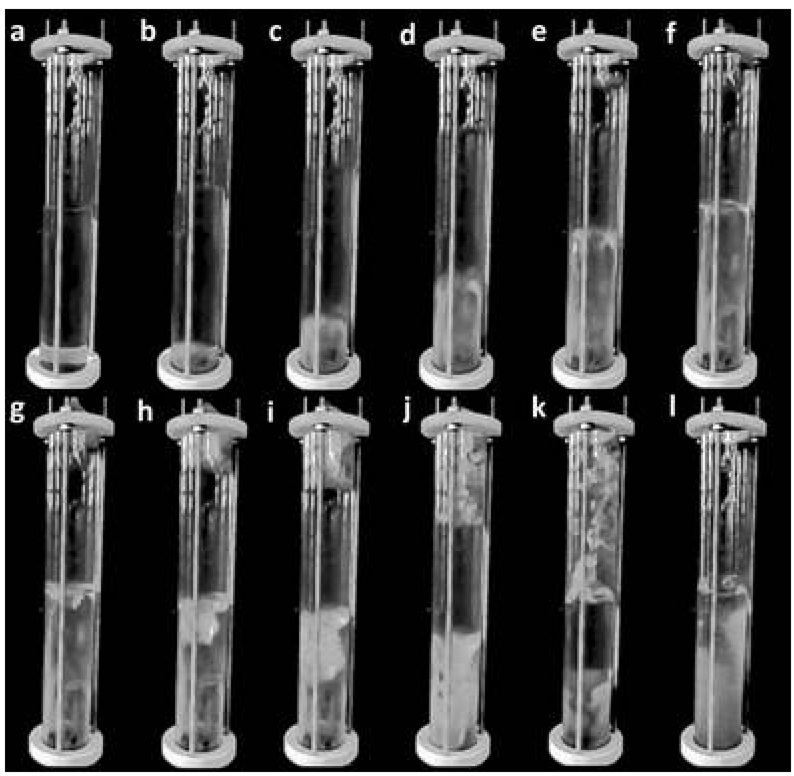

Figure 4. Expansion of the cavity and formation of the piston like movement of the water in the container.

Another phenomenon that can be inferred from the observations is the conversion of vapor into water and *vice-versa* during the evolution of the phenomenon. When the “water piston” strikes the top of the container the total “inversion of phases” is observed, that is, only vapor exists at the lower part and only water exists at the upper part of the container. No vapor bubbles trespass the liquid column, so that the vapor above the liquid seems to suffer a very quick rate of condensation. In this way, the rapid condensation counterbalances the growing bubble at the lower part, allowing expecting an almost constant pressure, or at least close to the vapor pressure at the temperature of the experiment.

Further, the water piston strikes the bottom of the container. This impact creates secondary bubbles close to the bottom and in the central region of the water piston. These bubbles, mainly at the central region, perform then an

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elastic-like process of growing and collapse, named “rebound” in the literature. Figure 5 shows a sequence of frames indicating one bubble going through the rebound process.

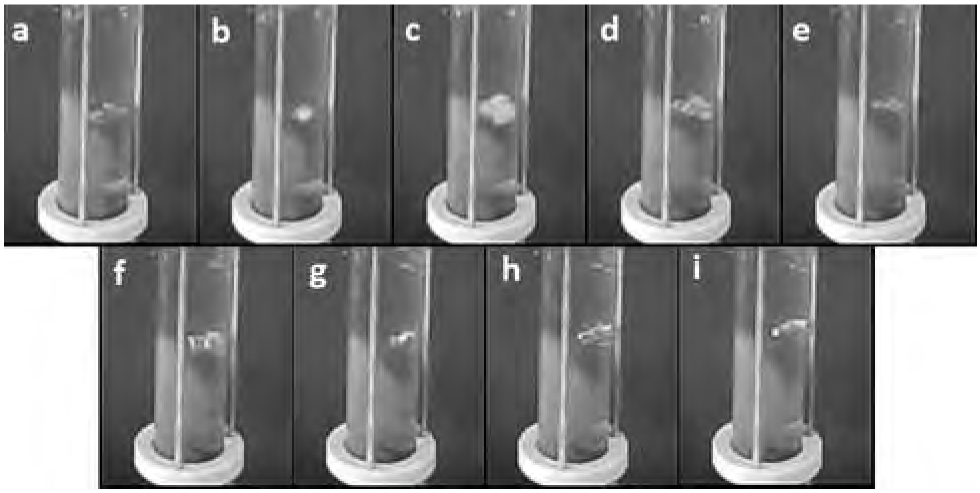

Figure 5. The rebounding process observed in the experiment. The total time of the experiment was 106,2 ms.

The “rebounding” works as a dissipative mechanism (similarly to a string, after being stretched and set free). Although most of the kinetic energy vanishes during the first implosion (or impact), the remaining amount of energy starts a process similar to the first one, generating a new bubble by “breaking” the metastable state.

Records made at specific parts of the container allowed observing different phenomena. As the upwards water starts to decrease its velocity, the central part of the liquid does not decelerate, forming a central jet that keeps the ascendant movement even after the rest of the water starts the downwards movement. This central jet only stops its movement after colliding with the top of the container, when it starts to descend, but still shaped as a jet.

Figure 6 shows the formation of the jet, from its growing to its collapse. The formation starts in Fig. 6c. The piston “appears” in Fig. 6f, and strikes the top of the container in Fig. 6k. In Fig. 6l it starts to go down.

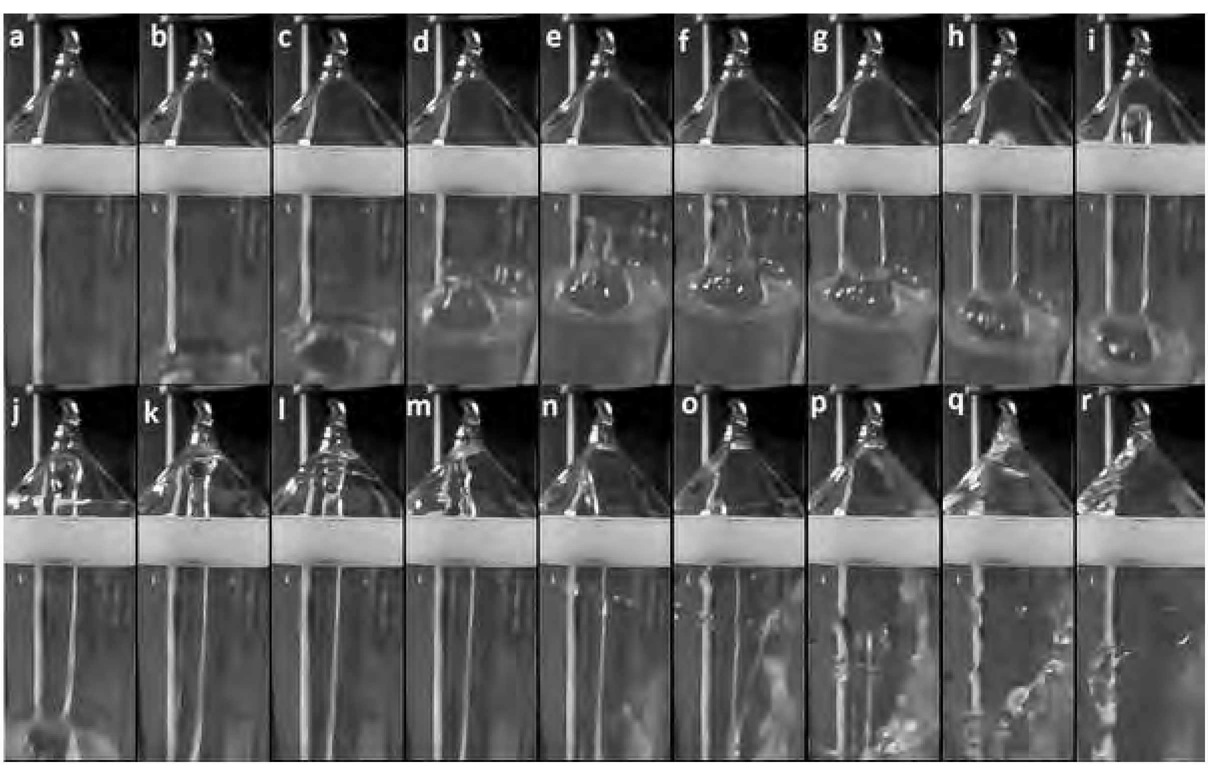

Figure 6. Formation and development of the central jet. The total time of the experiment was 343,7 ms

It is important to mention that the observed jet has a maximum length of about 20 cm, that is, it is also a macro-scale jet observed in a macro-scale cavitation event. In this sense, the present experiment allows observing in a simpler way phenomena described for smaller cavitation events.

Following the description of the vertical water jet, at its top a droplet may be observed. This formation is known as Rayleigh-Plateau Instability, and having an appropriate space, the droplet tends to separate from the main jet. This separation was not visualized in the current experiment, but the instability is present. This phenomenon is well described in literature of bubbles dynamics. For example, Pearson, *et al.,* (2003) describe the collapse of micro bubbles numerically, showing the appearance of the central jet at the lower and top faces of the water segment. Franc, *et al.,* (2004) also describe the formation of central jets at collapsing bubbles, mentioning that close to free surfaces the bubbles form jets in both directions. Schulz, *et al.,* (2012), in theirs experiments, only observed the formation of the jet at the inner face of the bubble, forming then the torus like cavity.

5. POSSIBLE GENERATION OF WORK

The phenomena described here, mainly the piston like movement, generate a great impact in the container. Using a system that allows the vertical movement of the container, it also moves like a piston. Although the purpose of this paper was not directed to measurements of force and displacement, Schulz, *et al*., (2012) observed force values that reached around 500 N. The dynamics of this macro cavities show that simple arrangements can produce usable work.

6 CONCLUSION

This paper presents the geometrical characteristics of experimental devices that allow the controlled generation of macro-scale cavities in liquids. The devices were tested to produce images of details of the movement of cavitation macro bubbles.

The obtained images allow observing the intense vapor-liquid conversions that occur in such phenomena, the fast rebounding events occurring for secondary bubbles, the formation of central macro-scale jets at the upper surface of the liquid, among other characteristics of liquids experiencing very fast changes.

It was also possible to verify the similarity between the dynamics of micro and macro cavities, pointing to the convenience of studying two-phase phenomena using macro-scale cavities. An example is the formation of the central jet in the upper surface of the liquid. The described characteristics were observed despite the fact that one-dimensional macro cavities were used.

The use of similar devices for the study of characteristics of cavitation through large-scale bubbles is thus highly recommended.

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