Spark bubble interaction with a suspended particle

Siew-Wan Ohl1,*, Di Wei Wu2, Evert Klaseboer1, Boo Cheong Khoo2

1Institute of High Performance Computing, 1 Fusionopolis Way, #16-16 Connexis North, Singapore 138632.
2Department of Mechanical Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260.

Corresponding author’s e-mail address: ohlsw@ihpc.a-star.edu.sg

Abstract. Cavitation bubble collapse is influenced by nearby surfaces or objects. A bubble near a rigid surface will move towards the surface and collapse with a high speed jet. When a hard particle is suspended near a bubble generated by electric spark, the bubble expands and collapses moving the particle. We found that within a limit of stand-off distance, the particle is propelled away from the bubble as it collapses. At a slightly larger stand-off distance, the bubble collapse causes the particle to move towards the bubble initially before moving away. The bubble does not move the particle if it is placed far away. This conclusion is important for applications such as drug delivery in which the particle is to be propelled away from the collapsing bubble.

1. Introduction

The interaction of cavitation bubbles with particles in suspension is of importance in erosion studies. It is proposed that the existence of cavitation bubble enhanced erosion effect [1]. However an experimental work done by Soh and Willis [2] report that the spark-generated cavitation bubble does not move the particles much during its expansion and collapse. In another study using shock wave generated bubbles, the bubble formed on the surface of a particle propels the particle forward as it collapses [3]. In this study, a spark-generated bubble is used to move the suspended particle as it collapses. Our cavitation bubble is much smaller (relative to the particle) as compared to that used in [2]. Observations are recorded using high speed photography.

2. Experimental setup

Figure 1 shows the experimental setup used in this study. It consists of a circuit to generate the spark bubble, a suspended particle (on string), and a high speed camera system. The details of the circuit are found in [4]. The particle is made of Perspex, and has a radius of 1.50 mm. It has a density of 2.5 g/cm³. It is suspended by a cotton thread of 0.12 mm in diameter. Different threads have been tested, and this thin thread is found to be affecting the movement of the particle to the smallest degree. We have also performed experiments where the particle is attached to a fixed thread by silicon oil, similar to [5]. In these cases, the string does not hinder the particle movement. Due to space limit, the results are not presented here. The spark bubble is generated at the crossing of two electrodes. The high speed photography system is made up of a high speed camera (Photron, SA1), and a LED spotlight. It is operated at 20,000 frames per second.
Fig. 1 The experimental setup in this study. The circuit to generate the spark bubble is given in details in [4]. Deionized water is used.

3. Results

3.1. Particle is pushed away

A series of bubble particle interaction experiment has been performed. Figure 2 shows the case where the particle is propelled away (to the left) from the cavitation bubble. The bubble (on the right) was generated at a stand-off distance of 2.73 mm from the particle. The initial expansion of the bubble pushes the particle away from its initial position. When it collapses, the bubble forms a ‘mushroom’ shape (t = 1.20 ms), and then split into two (t = 1.25 ms). The part of the bubble on the particle pushes the particle to the left as it re-expands and collapses again. The other part of the bubble collapses and jets away from the particle.

Fig. 2 Interaction of a cavitation bubble with a suspended particle during the bubble’s collapse phase. The particle moves away from its initial position to the left. The maximum bubble radius is 3.99 mm (not shown). Framing rate is 20,000 frames per second

3.2. Particle moves towards the collapsing bubble

However, if the spark bubble is generated slightly further from the suspended particle, the particle is initially pushed away as the bubble expands. When the bubble collapses, the particle is attracted towards the collapsed bubble. The movement of a suspended particle which is initially 5.16 mm away from a spark bubble is presented in Figure 3. The bubble obtains its maximum size of 4.05 mm at t = 0.95 ms. Then it collapses forming a ‘neck’ on the particle (t = 1.35 ms). The bubble collapses at t = 1.40 ms (not shown). The particle moves to the right after the bubble has collapsed (t = 12.5 ms).
Fig. 3 Interaction of a cavitation bubble with a suspended particle where the particle moves towards the bubble after it has collapsed. The stand-off distance is 5.16 mm. Framing rate is 20,000 frames per second.

A larger Perspex particle of 2.0 mm radius is also tested. Its movement is dependent on the stand-off distance, $S$. Figure 4 shows the initial velocity of the particle after the bubble collapse. The stand-off distance is non-dimensionalized to $S'$ by dividing $S$ by the maximum bubble radius, $R_{\text{max}}$, which varies slightly around 4 mm. The cases in Figure 2 and 3 have $S' = 0.68$ and 1.27, respectively. Within experimental error, the initial velocities for both particles are similar. This has been confirmed by a recent study [5] where 6 different particles are used.

![Image of particle interaction](image)

Fig. 4 The initial velocity $V$ of a suspended particle of radius 1.50 mm (blue), and 2.0 mm (red) after the oscillating bubble next to it has collapsed.

### 3.3. Effect of the stand-off distance

The effect of the stand-off distance on the bubble particle interaction is summarized in Figure 5. The distance is non-dimensionalized with $R_{\text{max}}$. It is shown that for a cavitation bubble which is generated about one bubble radius away (1.14), the particle will be displaced away from the spark bubble as it collapses. However a non-dimensionalized stand-off distance between 1.14 to 1.85, the particle will move towards the collapsing bubble. If the particle is placed far from the spark bubble (non-dimensionalized stand-off distance larger than 1.85), it is not moved as the bubble expands and collapses spherically.
Fig. 4 Summary of the maximum displacement of the suspended particle with different non-dimensionalized stand-off distances from the spark bubble. For the particles that are close to the bubble (S’ < 1.14), the particles are pushed away from the bubble after its collapse. For particles that are a bit further from the bubble, they move towards the bubble after its collapse. Similar observation is reported in [5]. For S’ > 1.85, the bubble has no influence on the suspended particle, and it remains unmoved.

4. Conclusion

This study shows that the movement of a particle next to a cavitation bubble is dependent on the stand-off distance between the two. We have also performed experiments using different particles and a slightly different suspension method. In all cases, the same phenomenon of repulsion and attraction within a range of stand-off distances is observed. Due to the space constrains, only results from one particle is presented. However in a recent article [5], it is found that the initial velocity of the particle is independent of the particle material and to some extent its size. In conclusion, we deem that it is important to place the cavitation bubble very close to the particle if the objective is to ‘shoot’ the particle away, for example in drug delivery [6, 7] or erosion enhancement.

References

[1] Dunstan, P. J., and S. C. Li. "Cavitation enhancement of silt erosion: Numerical studies." Wear 268, no. 7 (2010): 946-954.
[2] Soh, W. K., and B. Willis. "A flow visualization study on the movements of solid particles propelled by a collapsing cavitation bubble." Experimental thermal and fluid science 27, no. 5 (2003): 537-544.
[3] Arora, Manish, Claus-Dieter Ohl, and Knud Aage Mørch. "Cavitation inception on microparticles: A self-propelled particle accelerator." Physical review letters 92, no. 17 (2004): 174501.
[4] Goh, B. H. T., Y. D. A. Oh, E. Klaseboer, S. W. Ohl, and B. C. Khoo. "A low-voltage spark-discharge method for generation of consistent oscillating bubbles." Review of Scientific Instruments 84, no. 1 (2013): 014705.
[5] Poulain, Stéphane, Gabriel Guenoun, Sean Gart, William Crowe, and Sunghwan Jung. "Particle Motion Induced by Bubble Cavitation." Physical Review Letters 114, no. 21 (2015): 214501.
[6] Pavard, Delphine, Evert Klaseboer, Siew-Wan Ohl, and Boo Cheong Khoo. "Removal of particles from holes in submerged plates with oscillating bubbles." Physics of Fluids 21, no. 8 (2009): 083304.
[7] Borkent, Bram M., Manish Arora, Claus-Dieter Ohl, Nico De Jong, Michel Versluis, Detlef Lohse, Knud Aage Mørch, Evert Klaseboer, and Boo Cheong Khoo. "The acceleration of solid particles subjected to cavitation nucleation." Journal of Fluid Mechanics 610 (2008): 157-182.