Interation between cavitation and gas bubbles near a rigid boundary

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Abstract The cavitation phenomenon causes abnormal vibration in high-speed hydraulic machines such as rocket turbopumps. To overcome this, studies are still being conducted by many researchers. At the same time, bubble dynamics are also being studied to elucidate cavitation phenomena such as liquid microjets that cause cavitation bubbles during collapse and shock waves that occur during rebounds. However, there are still unknown details because aspheric motion of bubbles, including the formation of microjets, is a fast-occurring phenomenon on the microscale; in particular, many points concerning bubble–bubble interactions remain unclear. In this research, in relation to the interaction between multiple bubbles, we experimentally investigated the mutual interaction between a gas bubble attached to a rigid wall and a cavitation bubble generated in the vicinity. The influence of the bubble size ratio on the direction of the liquid microjet formed in the cavitation bubble is discussed.

Keywords: cavitation bubble, gas bubble, interaction, liquid microjet, rigid boundary

1 Introduction

The cavitation phenomenon is widely known as the main cause of abnormal vibration during erosion and rocket turbopumps in hydraulic machines, so researchers have tried to elucidate the cavitation phenomenon [1]. In particular, the cavitation erosion is thought that the microjet forms when the cavitation bubble collapses near the wall and the shock pressure generated by the shock wave emitted at the time of repeated rebounds. Therefore, to improve the reliability and durability of fluid machines, reducing the impact pressure caused by liquid microjets has long been one of the major issues. On the other hand, in the life science and medical fields, the technique of forming micropores in the cell wall by irradiating microbubbles with ultrasound, known as sonoporation, has attracted attention [2]. The drug delivery system is a technology that controls the transport of the administered drug capsule in the body and supplies the drug to the affected area at an appropriate position and time. Sonoporation technology improves the rate of drug absorption when the affected area is irradiated with ultrasound. Therefore, the bubble-dynamics approach has been stated to elucidate the mechanism of sonoporation, and it is expected to elucidate in more detail the behavior of the interaction between microjets and bubbles.

However, owing to the mutual interactions of multiple bubbles, the phenomenon is complicated, and there are many parameters that affect the mechanism of determining the direction of the microjet formed as a result of the mutual interaction of multiple bubbles, which remain unclear.

In this research, the interaction between a gas bubble attached to a rigid wall and a cavitation bubble generated in the vicinity was investigated experimentally in relation to the interactions between multiple bubbles. A discharge was used to generate the cavitation bubble, and the phenomenon was photographed with a high-speed camera. The effect of the bubble size ratio on the direction of the liquid microjet formed in the cavitation bubble was mainly discussed.

2 Experimental Device and Methods

Figure 1 shows a schematic diagram of the experimental setup. The water tank used for the experiment is a rectangular glass parallelepiped container of dimensions $W = 600\ mm \times D = 300\ mm \times H = 360\ mm$ and is
filled with tap water. On the top of the water tank, an electrode holder is installed for generating a cavitation bubble, and an acrylic disk ($\varnothing$ 100 mm, $t = 3$ mm) is used as the rigid wall. A 0.3 mm tungsten electrode was used. Gas bubbles were generated on the underside of the acrylic disk with a syringe. The cavitation bubble was generated by the discharge coaxially in the vicinity of the gas bubble, and the behavior of the bubbles was regarded as almost axisymmetric motion. The distance between the cavitation bubble center and the wall ($I$) was adjusted by changing the height of the acrylic disk. The bubble interactions were captured using a high-speed camera (Photron FASTCAM-MAX 120K) with a metal halide lamp (Photron HCV-SL) as the light source. The growth and collapse of bubbles are very high speed phenomena, so the capture speed was 30000 fps and shutter speed was 1/250000 [s].

![Schematic of experimental equipment](image)

**Fig. 1 Schematic of experimental equipment**

### 3 Results and Discussion

In this paper, we show high-speed imaging results obtained under the condition of relative distance $\gamma_c = l / R_{C,max} = 2.2$ to 2.5 between the wall and the cavitation bubble. The photograph frame interval is $\Delta t = 33.3$ [$\mu$s]. Figure 2 illustrates the behavior observed for a cavitation bubble generated near the wall surface. The experimental conditions at this time are the maximum cavitation bubble radius $R_{C,max} = 2.41$ mm, bubble–wall distance $l = 5.37$ mm, and bubble–wall relative distance $\gamma_c = 2.23$. Although this picture is not clear, at the end of the first period of nonlinear oscillation (13 frames), a microjet is formed toward the wall and drawn to the rigid wall side. This result is consistent with the previous research results [3][4].

![Dynamic behavior of the cavitation bubble near a rigid wall](image)

**Fig. 2 Dynamic behavior of the cavitation bubble near a rigid wall ($R_{C,max} = 2.41$ mm, $l = 5.37$ mm, and $\gamma_c = 2.23$)**
Figures 3–5 discuss the behavior in the presence of a gas bubble between the wall and the cavitation bubble. \( \gamma_c \) is kept approximately constant (\( \gamma_c = 2.50, 2.53, \) and 2.52 in Figures 3, 4, and 5, respectively), and the size ratio \( R^* = R_{c,max} / R_{a,0} \) of the cavitation bubble maximum radius \( (R_{c,max}) \) to the gas bubble initial radius \( (R_{a,0}) \) is regarded as the main parameter.

Figure 3 shows the experimental results for \( R^* = 0.43 \) where the gas bubble size is relatively small. Owing to the small size ratio, the effect of the gas bubble motion on the cavitation bubble behavior is limited; it is observed that the cavitation bubble is drawn to the rigid body wall side, as shown in the previous figure.

![Fig. 3 Interactions between the cavitation and gas bubbles near a rigid wall (\( R_{c,max} = 2.24 \, mm, \, R_{a,0} = 0.95 \, mm, \, l = 5.59 \, mm, \, R^* = 0.43, \) and \( \gamma_c = 2.50 \))](image)

Figure 4 shows the results for \( R^* = 0.64 \). Under this condition, microjets are not formed in the cavitation bubble, and no translational movement is observed. In other words, it can be seen that the cavitation bubble moves almost spherically under this condition. This suggests that the gas bubble is effective at reducing the effect of asymmetry (rigid wall) on the cavitation bubble in an asymmetric flow field in which a rigid wall is present near the bubbles.

![Fig. 4 Interactions between the cavitation and gas bubbles near a rigid wall (\( R_{c,max} = 1.75 \, mm, \, R_{a,0} = 1.13 \, mm, \, l = 5.31 \, mm, \, R^* = 0.64, \) and \( \gamma_c = 2.53 \))](image)
Figure 5 shows the results obtained under the condition $R^* = 0.98$, where the sizes of the cavitation and gas bubbles are almost equal. In this figure, it is observed that the cavitation bubble moves to the opposite wall surface while forming a jet. The large size of the gas bubble compared to that in the previous figure indicates that the behavior is similar to the motion of the cavitation bubble generated near the free surface [5]. Under this condition, the influence of the rigid wall on the cavitation bubble does not appear explicitly. In the experimental results in Figures 3–5, it is clear that the direction of the jet generated by the cavitation bubble and the translational direction depend on the size ratio of the cavitation bubble to the gas bubble. In addition, the behavior of the gas bubble is impacted by the movement of the cavitation bubble, and jet formation and nonlinear vibration in the gas bubble are observed. Thus, they both interact and the movement of the cavitation bubble in Figure 5 is considered to be a phenomenon that should be distinguished from that of the cavitation bubble near the free surface.

![Figure 5](image)

Fig. 5 Interactions between the cavitation and gas bubbles near a rigid wall ($R_{c,am}=1.82 \text{ mm}, R_{a,0}=1.78 \text{ mm}, l = 4.59 \text{ mm}, R^*=0.98, \text{ and } \gamma_{c}=2.52$)

4 Conclusion

We attempted to clarify the interaction between a gas bubble attached to a rigid wall and a cavitation bubble generated in the vicinity. The single cavitation bubble near the rigid wall forms a liquid microjet toward the wall and is drawn toward the wall side, whereas if the gas bubble is present between the wall and the cavitation bubble, the microjet of the cavitation bubble and the direction of translational motion are found to depend on the size ratio of the cavitation bubble to the gas bubble.

References