# Behavior of bubble pulse in food processing using underwater shock wave

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**ABSTRACT**

The food processing technology using a shock wave can prevent deterioration of the food by heat because it can process food in a short time. However, in order to process safely, it is important to clarify the behavior of the shock wave because the action to the food by a shock wave is complicated.

In this research, in order to investigate the behavior of the shock wave in the container used for food processing, the optical observation experiment and the numerical simulation were performed. In the experiment, the bubble pulse generated by explosion was observed with the high-speed video camera. The numerical simulation about the behavior of bubble pulse was performed using analysis software LS-DYNA.

Comparing and examining were performed about the experimental result and the numerical simulation result. The shock wave generated by explosion, the shock wave generated by the bubble pulse of the explosion gas, and the behavior of the bubble pulse was confirmed.

## 1. INTRODUCTION

The conventional technique using an explosive or a shock wave is called explosive processing. Explosive forming, Explosive welding, Explosive synthesis, Explosive cutting (Shaped charge) etc. are included in this processing. These techniques are not simply used as destruction. In recent years, the food processing technique using the shock wave generated by an explosive etc. as the new explosive processing method is attracting attention. For example, if this technique is used, softening processing of an apple, a pineapple, etc. can be performed using a shock wave. The excellent features in food processing using a shock wave are that processing time is dramatically short, that there is little influence of heat on food, that the deterioration of the food by processing is small, that there is a bactericidal effect, etc.

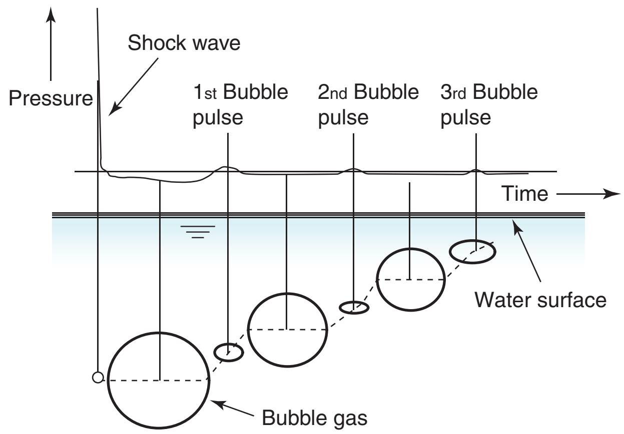



Figure 1 Schematic illustration of underwater explosion phenomenon.

The shock wave used for the food processing is generated from the explosion of explosive and pulse power of a high voltage. In order to control the strength of the shock wave generated by these, the underwater shock wave is used for general food processing using a shock wave. However, because the history of food processing using the underwater shock wave is short, the details of shock wave processing are not clarified enough.

The underwater shock wave that processes food is known as a fundamental phenomenon of underwater explosion [1]–[5], and there are a shock wave generated by initial explosion and a shock wave generated by the explosion product gas. A bubble gas presents the complicated behavior that repeats expansion and contraction, and the shock wave called a bubble pulse is generated at the time of contraction. The Schematic illustration of an underwater explosion phenomenon is shown in Figure 1. It has been considered that the bubble pulse, which has the feature that action time is long although the maximum pressure is small compared with a shock wave, is important when calculating the shock response of marine structures, such as a vessel. Although many researches have been conducted about research of a shock response of these structures, research on the behavior of the underwater shock wave in the very near field of a shock wave source that is used by food processing is not fully conducted.

In this research, fundamental investigation was conducted about the behavior of the shock wave generated by expansion contraction of the detonation product gas which occurred by the explosive (bubble pulse) as part of development of food processing device which used the shock wave. In order to investigate the behavior of a bubble pulse, the optical observation using a high-speed video camera and a numerical simulation were performed.

## 2. EXPERIMENTAL PROCEDURE AND NUMERICAL SIMULATION METHOD

### 2.1. EXPERIMENT

The schematic experimental setup used by this research is shown in Figure 2. A water container is made of steel and is 1.2 m in length, 3.2 m in width, and 1.8 m in depth. The explosive was arranged and initiated at the center of a water container. The image measurement by a high-speed video camera estimated the bubble gas generated by the explosion of an explosive. The water container was filled up with water to 1.6 m, and the explosive was hung from the upper

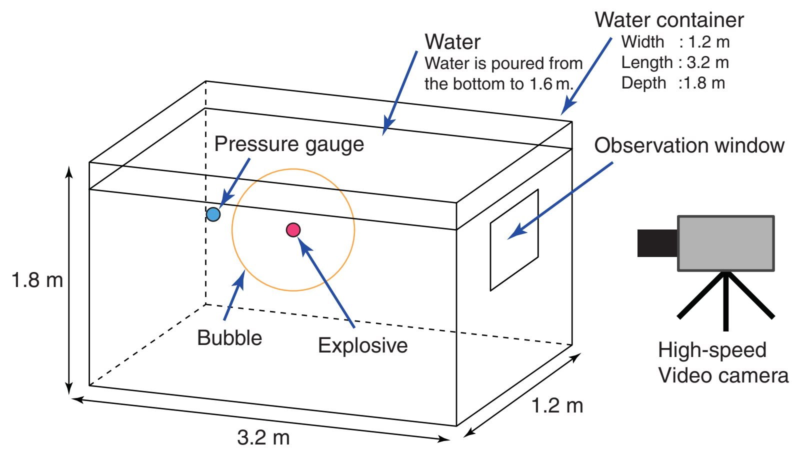



Figure 2 Experimental setup.

part. The observation window is prepared in the side panel of the water container, and high-speed photography was performed through this window. The No. 6 electrical detonator was used for the explosive. In order to consider the influence of the water surface, the water depth of the center position of an explosive was changed with 200,300,400 mm. Photography at a recording speed of 2,000 fps was performed using the high-speed video camera (Phantom V7.3, Vision Research, Inc., Resolution: 800 × 600 pix).

## 2.2. NUMERICAL SIMULATION

Commercial analysis software LS-DYNA was used for numerical simulation. [6], [7] Figure 3 shows a calculation model in this research. The numerical simulation about this experiment was considered to be a symmetrical problem, and analysis of quarter symmetrical model that

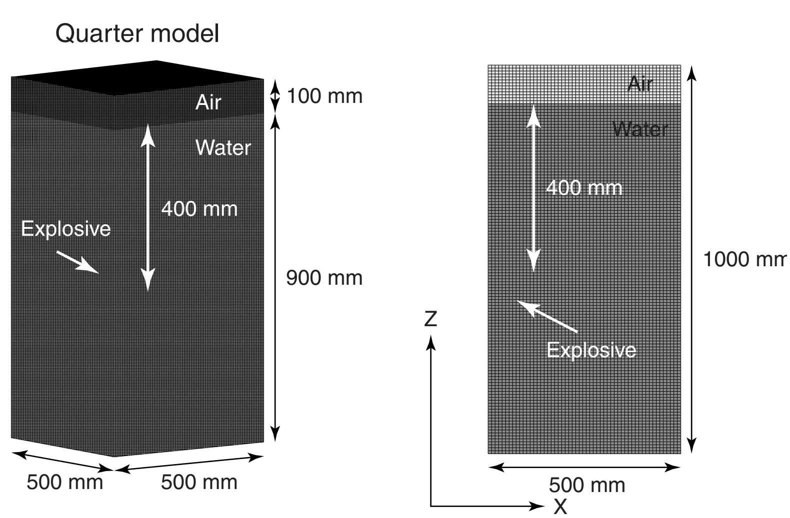



Figure 3 Schematic illustration of calculation model.

used the calculation field of 0.5 m in length, 0.5 m in width, and 1.0 m in height was conducted. The calculation field that set upside air to 0.1 m and set depth of water to 0.9 m was used. The position of the explosive was 200 mm, 300 mm, and 400 mm from the water surface like the experiment, and the numerical simulation in each case was performed. The multi-material Euler method was used for the calculation method. The technique with which the detonation propagation technique of an explosive combined C-J volume Burn and Programmed Burn was adapted. [6]–[8] A 10 mm cube element was created, and the number of elements was set to 250,000.

The numerical simulation for an explosive, air, and water was conducted using the multi-material Euler method. The JWL equation of state [9]–[11] was used for the equation of state to show the detonation of the electrical detonator. The JWL parameter of high explosive SEP was used in this numerical simulation instead of the JWL parameter of the electrical detonator. [12] Moreover, since the size of the calculation mesh was larger than the size of an actual electrical detonator, the shape of the explosive used for this simulation was made into a spherical explosive 10 mm in radius. The initial energy value of the explosive was adjusted so that the energy of a 0.6 g SEP explosive might be released. The equation of state of ideal gas was used for Air. The Gruneisen equation of state was used for water.

## 3. RESULTS AND DISCUSSION

### 3.1. EXPERIMENTAL RESULTS

The high-speed photography image in the depth of water of 400 mm is shown in Figure 4. The bubble gas occurred from the moment of explosion and the phenomenon that a bubble gas repeated expansion and contraction were observed. In all experimental conditions, the shape of the bubble at the 1st cycle was approximately spherical. However, when it became the 2nd cycle and the 3rd cycle, the bubble shape in the case where depth of explosive is 400 mm was spherical, but as the depth of the water became shallow, shape collapsed in order of 300 mm, 200 mm greatly. The photograph of a bubble gas with which shape was distorted is shown in Figure 5.

The movement of the bubble gas is affected by the boundary surfaces such as a free surface or the structure greatly. The behavior of the bubble gas near the rigid body wall is shown in Figure 6. Because the flow to the direction of a center in case a bubble gas contracts becomes weaker near the rigid body wall, it becomes impossible for a bubble gas to contract equally. Therefore the flow of a side far from a wall becomes strong, and a bubble gas approaches the wall side. In this experiment, since the water container that is a finite region was used, it becomes easy to move the water of the explosive upper part as the position of an explosive becomes shallow. It is considered that the shape of the bubble gas in the experiment whose depth of an explosive is 200 mm changed by such reason rather than the experiment whose depth of an explosive is 400 mm.

The history of the diameter of the bubble gas obtained in the experiment is shown in Figure 7. The maximum diameter of the bubble gas of the first cycle of three conditions was about 280 mm, and was the almost same size. However, a few difference appeared in change of the diameter of the bubble gas at the 2nd and 3rd cycle for the influence of the water pressure by the difference in the depth, and the influence by the shape of spherical bubble gas having been distorted.

Figure 8 shows the displacement history about the center position of the bubble gas. All the bubble gases of three conditions settled down. As mentioned above, since it would be easy to move the water of the explosive upper part if the position of an explosive becomes

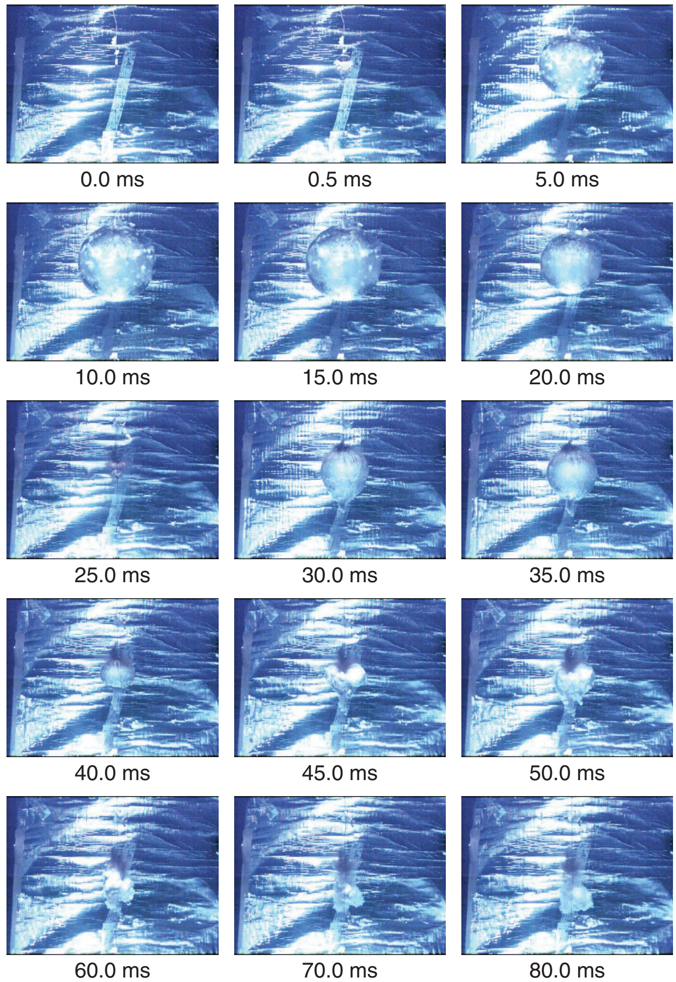



Figure 4 High-speed photography images in the depth of water of 400 mm.

shallow, the amount of descent of bubble gas increased as the position of the explosive became shallow.

Moreover, the diameter of the bubble gas and the descent of the bubble gas in each experimental condition were shown in Figure 9. It was able to be confirmed that the bubble gas moved intensely at the time of contraction by the experiment results.

Comparison of a pressure measurement result, the diameter of the maximum bubble, and the displacement of the bubble gas is shown in Figure 10. Thus, it has confirmed that the shock wave had occurred at the time of contraction of a bubble gas.

### 3.2. NUMERICAL RESULTS

The image of the bubble gas obtained by the numerical simulation in case the depth of an explosive is 400 mm is shown in Figure 11. The bubble gas is generated because an explosive explodes, and the appearance where it repeats expansion and contraction can be simulated.

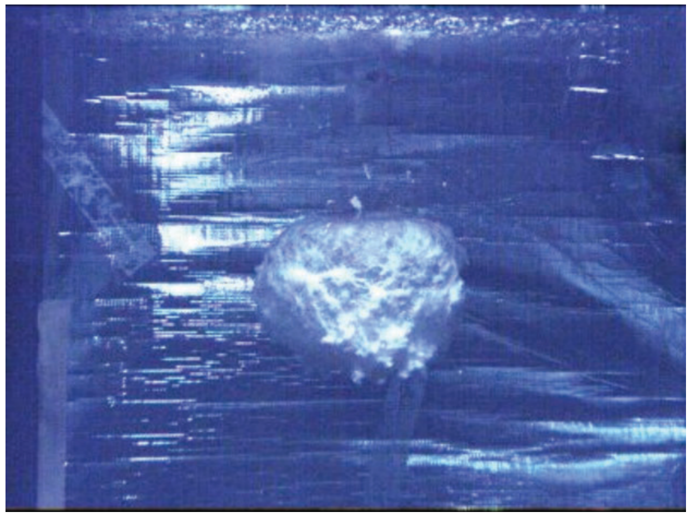


Figure 5 Photograph of a bubble gas with which shape was distorted in the depth of 200 mm at 40 ms.

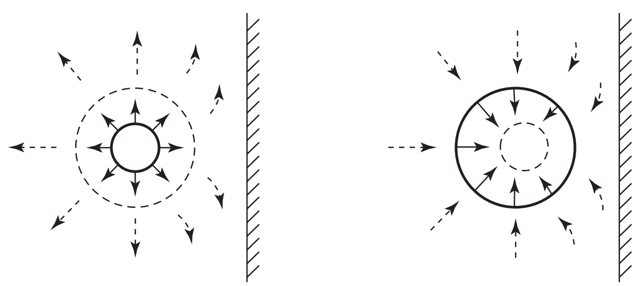



Figure 6 Behavior of the bubble gas near the rigid body wall.

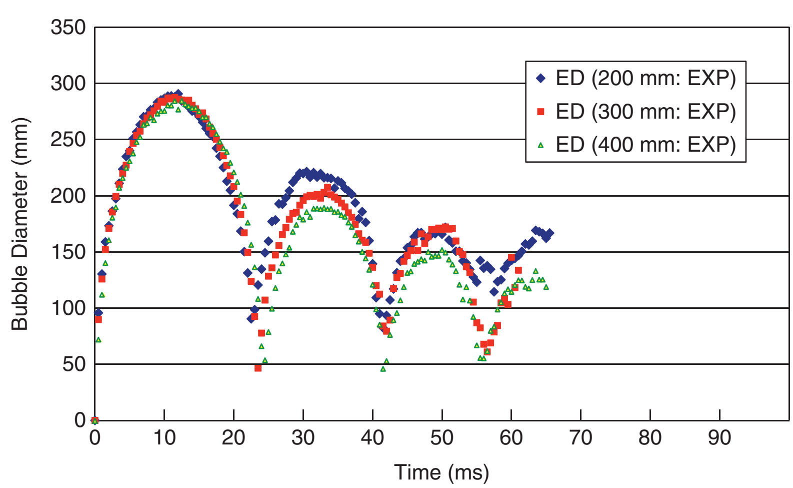



Figure 7 History of the diameter of the bubble gas obtained in the experiment.

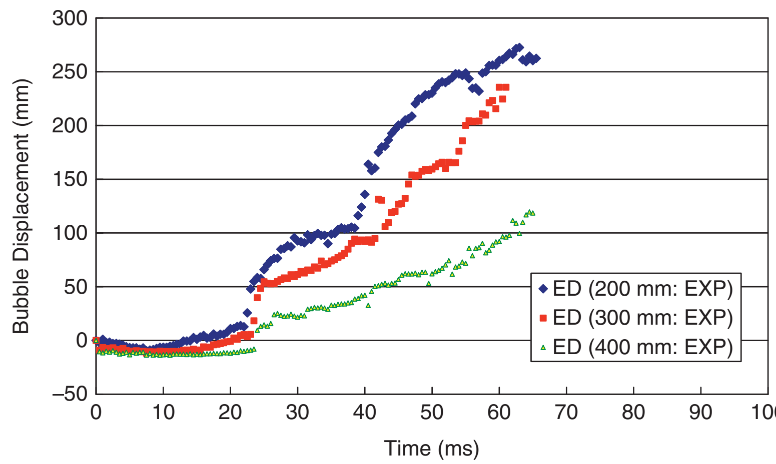



Figure 8 Displacement history about the center position of the bubble gas.

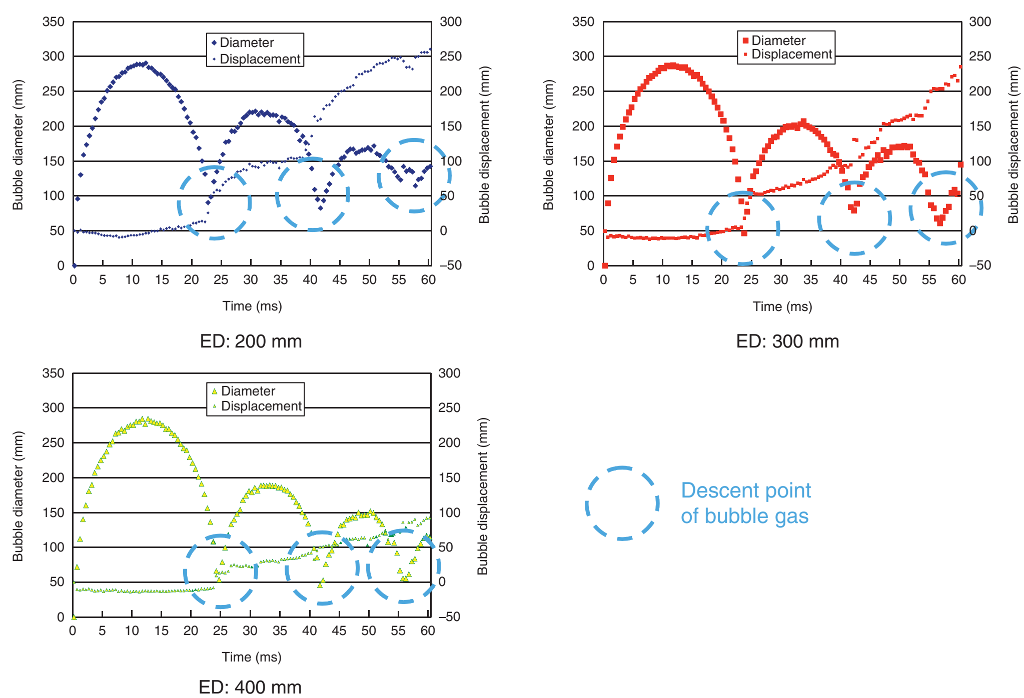



Figure 9 Diameter of the bubble gas and descent of bubble gas.

Figure 12 shows the image of the bubble gas at the second cycle when the depth of an explosive is 200 mm and 300 mm. In these conditions, the spherical bubble gas at the 2nd cycle was distorted greatly, and moved downward without carrying out expansion contraction. The diameter of the bubble gas and the amount of descent of bubble gas obtained from numerical simulation in each condition are shown in Figure 13. Because the shape of the bubble gas had collapsed when the depth of explosive was 200 mm, and 300 mm, it indicated on the way in the second cycle. When bubble gas in case the depth of an explosive is 200 mm and 300 mm contracted, bubble gas descended greatly, but in the case of 400 mm, it did not descend greatly.

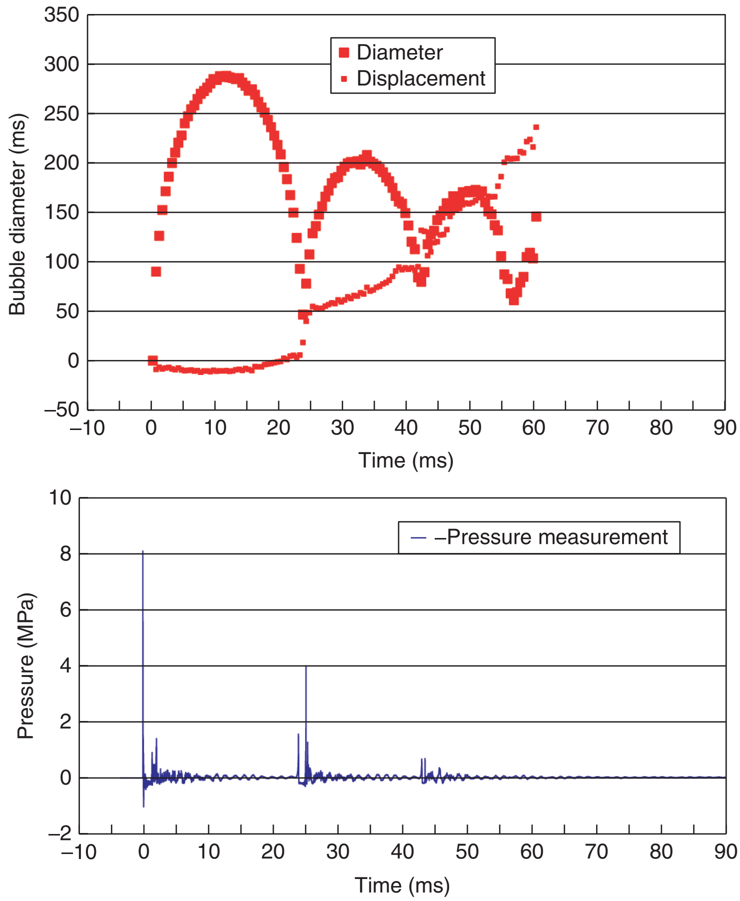



Figure 10 Comparison of pressure measurement result, maximum diameter of bubble, and displacement of bubble gas.

## 3.3. COMPARISON OF RESULTS AND DISCUSSION

Comparison of the outer diameter of bubble gas is shown in Figure 14. The experiment result and the calculation result for the expansion contraction history of the bubble gas at the first cycle corresponded mostly. As for the size of expansion contraction of the bubble gas after the 2nd cycle in case the depth of an explosive is 400 mm, the calculation result became smaller than an experimental result. Because the size of the calculation mesh is coarse, it is considered that movement of the water of the explosive upper part became small as the reason. In addition, it is considered that the influence of the water container wall appeared greatly because a water container in finite region was used by the experiment.

Figure 15 shows the comparison of the displacements of the bubble gas. Displacement of the bubble gas of an experiment became larger than a calculation result. It is considered as a reason that the size of a calculation mesh is not fine enough and that the difference of the displacement between experimental results and numerical results appeared since the influence of the water container wall in an experiment was great. Figure 16 shows the comparison of the pressure measurement results. The pressure peak value of the first wave of an experimental result was 8.1 GPa, and it was 8.7 GPa for the numerical result, and a corresponding result was

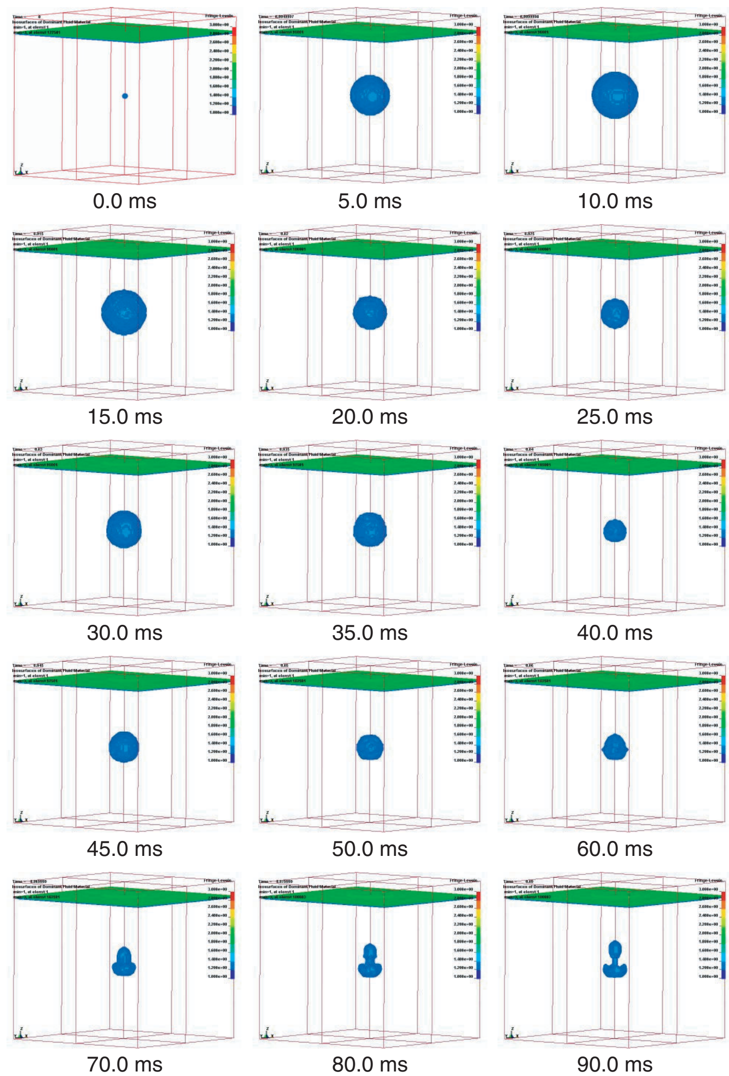


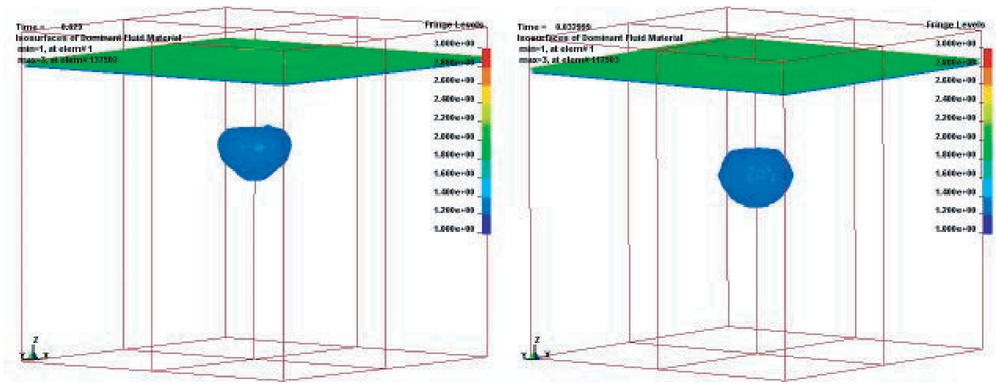

Figure 11 Image of bubble gas obtained by numerical simulation in case depth of explosive is 400 mm.

obtained. However, although the pressure values of the 2nd pulse wave differed greatly, time for a shock wave to reach a measuring point was almost the same.

As overall consideration, when the influence of the size of a calculation mesh etc. was taken into consideration, the experiment result and the numerical result were mostly in agreement, and the good result was obtained. In order to simulate a more exact numerical computation result, it is necessary to make the size of a calculation mesh fine and to model the whole including the influence of the wall of a water container etc.

## 4. CONCLUSION

In this research, fundamental investigation was conducted about the behavior of the shock wave generated by expansion contraction of the detonation product gas which occurred by



(1) 200 mm (at 29 ms) (2) 300 mm (at 33 ms)

Figure 12 Image of bubble gas at 2nd cycle when depth of explosive is 200 mm and 300 mm.

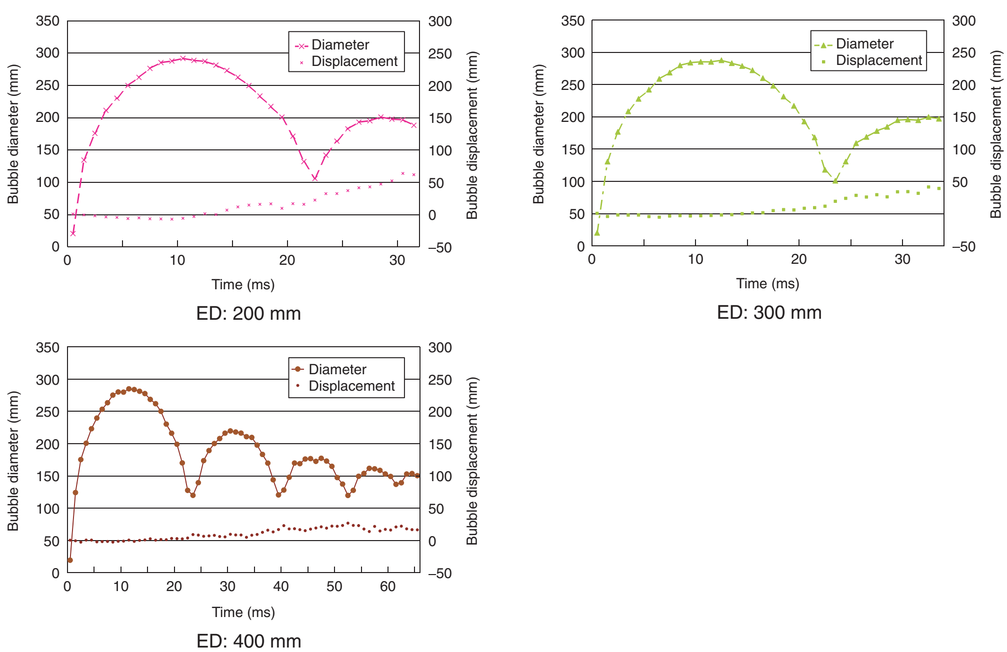



Figure 13 Diameter of bubble gas and descent of bubble gas obtained from numerical simulation in each condition.

the explosive (bubble pulse) as part of development of food processing device which used the shock wave. In order to investigate the behavior of a bubble pulse, the optical observation using a high-speed video camera and a numerical simulation were performed. The following results were obtained.

1. About the behavior of the bubble pulse when depth of water that uses the water container of a laboratory is comparatively shallow, it was understood that the influence by the water surface and influence with a water container wall are great.

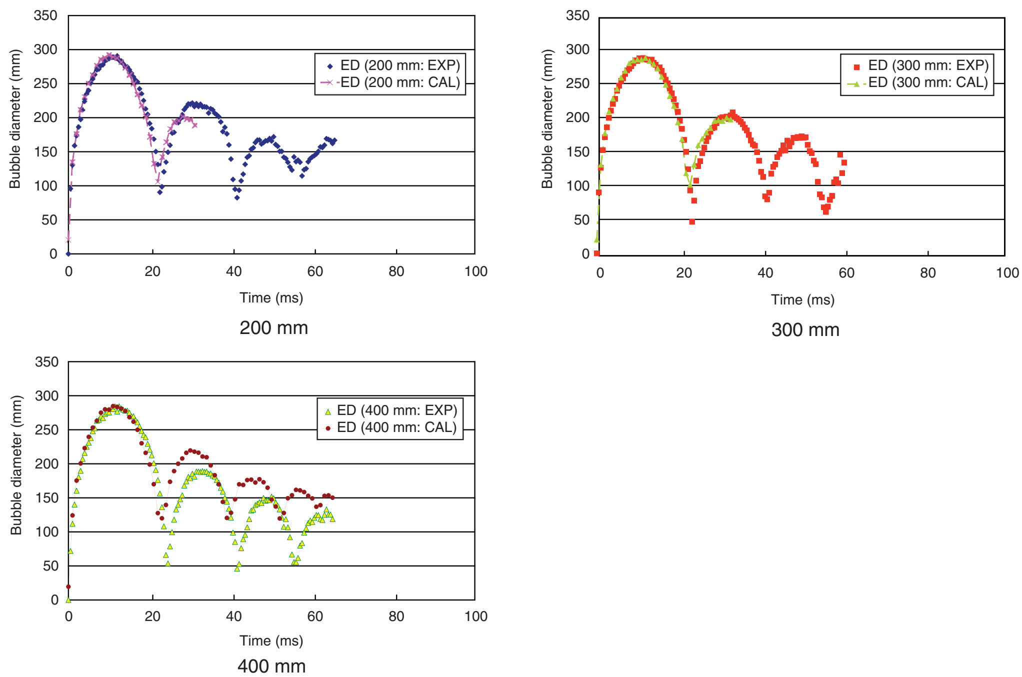



Figure 14 Comparison of the outer diameter of bubble gas.

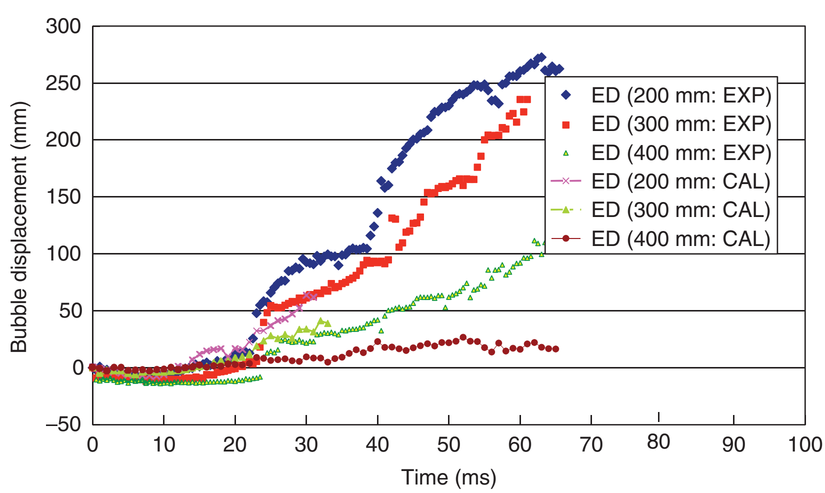



Figure 15 Comparison of displacements of bubble gas.

2. It has been understood that the strong water current to the lower direction is generated by the influences such as air and container walls, and the bubble gas descends in the water container of the finite region.
3. In the numerical simulation, the same behavior of expansion contraction of the bubble gas and the shock wave generated by bubble pulse as an experimental result were able to be simulated.

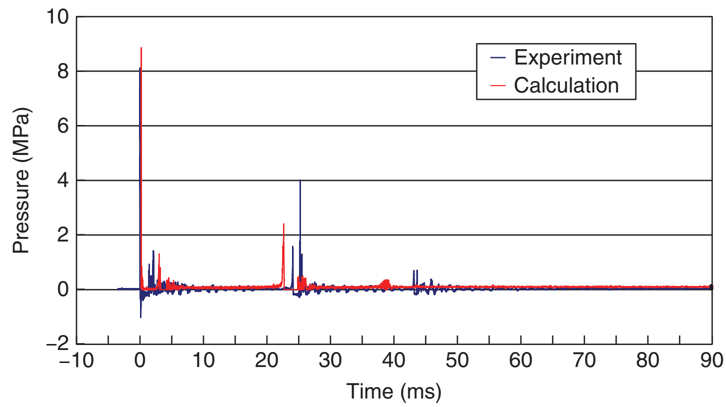



Figure 16 Comparison of the pressure measurement results.

4. It was confirmed that the result depended on a numerical simulation is appropriate, and it was demonstrated that a numerical simulation for development of the food processing device using a shock wave is an effective tool.

## 5. ACKNOWLEDGMENT

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