B218 Single Bubble Breakup

Warjito^o, Osamu MOCHIZUKI and Masaru KIYA

Division of Mechanical Science, Graduate School of Engineering, Hokkaido University
Kita-13, Nishi-8, Kita-ku, Sapporo 060-8628

ABSTRACT

The behavior of a single bubble undergoing a steep pressure gradient in vertical upward flow was studied by flow visualization to find a cause of noises emanating from components of a piping system. A high-speed video camera and still camera were used for observing the dynamics of a bubble. It was found that the steep pressure gradient strongly affected the bubble breakup. The investigation on a breakup mechanism revealed that an inward protrusion toward low-pressure side in a bubble formed just before the breakup.

Keywords: Bubble breakup, High-speed video camera, Still camera.

Introduction

Cavitation is a major source of noises in components of piping systems. However, we have heard the noise occasionally in spite of a low water flow rate. A water flow in practical situation frequently contains bubbles. When the bubbles sustained a pressure change, they began to deform and vibrate. According to a degree of a pressure gradient, the bubbles may break up near the components and make noise. Thus, the bubbly flows easily generate noises and vibrations at the components even if the cavitation does not occur.

There are many studies related to bubble dynamics in components of a piping system [Schmidt and Friedel (1997), Ivany et al. (1966) Mitchell and Hammitt (1973) and Wang and Brennen (1998)]. However, the information about a noise generation related to the breakup mechanism of bubbles is still lacking.

The purpose of this study was to investigate the effect of pressure gradient on single bubble breakup. A high-speed video camera and still camera were used for visualizing the behavior of a

bubble when it sustained a sudden pressure change.

Experimental setup

The experimental setup consisted of a water loop, test section, mixer and deaerator tank. The schematic figure of the whole experimental setup is sketched in fig. 1. The test section was made of an acrylic pipe with inner diameter, d of 51 mm and length of 300 mm. An orifice of 5 mm in thickness and 16 mm in hole diameter D was set in the middle of the test section. The dimensional contraction ratio, $\beta (= D/d)$, of the orifice was 0.314.

Fig.1 Schematic figure of experimental setup.

Results

Single bubble breakup

Instantaneous photographs of a bubble for different positions near the orifice are presented for water flow rate Q_w of 10 l/min is shown in fig. 2. These photographs were taken at different times, so that this is not a time series of one bubble. However, we obtained the same shape of the bubble at the same position, and we can therefore regard the pictures arranged for several positions as a sequence of bubble breakup.

Fig. 2 Instantaneous shape of a single bubble at different positions from the orifice for $\Delta p = 1.17$ kPa ($Q_w = 10$ l/min).

When the bubble entered the hole of the orifice, the bubble was squeezed and elongated in the flow direction, as seen in fig. 2. The stem of bubble became almost flat when the bubble passed through the orifice. Since the pressure gradient was negative, the pressure acting on the stem was higher than that acting on the bow. Thus the stem was pushed and the bow was pulled. At the next moment, an inward protrusion toward the downstream direction in the bubble was growing, as seen in the photographs of $x/D = 0.47-0.94$.

Fig. 3. Instantaneous shape of a single bubble at different positions from the orifice for $\Delta p = 3.42$ kPa ($Q_w = 18.3$ l/min).

Many small bubbles were produced just after the protrusion hit the bow. This is the breakup of a bubble.

Figure 3 shows the formation of protrusion in a bubble for $Q_w = 18.3$ l/min. In this case, the protrusion hit the bow at $x/D = 0.62$, in contrast to $x/D = 0.94$ in the case of $Q_w = 10.0$ l/min. It was clear that the protrusion hit the bow more rapidly as Q_w increases further.

Breakup frequency

The sequential image of a single bubble passed through the orifice was captured by a high-speed video camera with 400 frames/sec, as shown in fig. 4. It was observed that the time evolution and breakup of a bubble follow the breakup mechanism, which have been discussed before. The bubble was squeezed and elongated as shown in frame No 5, and then an inward protrusion toward the downstream direction in the bubble was growing as shown in frame No 6. The breakup position was determined as position where the protrusion hit the bow of bubble, as seen in frame No 11.

The movie was processed by a computer for measuring bubble size, location and frequency of breakup of a bubble. The frequency of breakup is defined as the percentage of the number of the breakup bubbles to the total number of bubbles with same equivalent bubble radius.

Here, we introduce non-dimensional pressure gradient p^* as follows.

$$p^* = r \frac{dp}{dx} \left(\frac{2r}{\sigma} \right), \dots \dots \dots (1)$$

where r is an equivalent bubble radius, dp/dx shows the pressure gradient and σ is the surface tension. Figure 5 shows a relation between p^* and frequency of breakup of a bubble. The frequency of breakup increased with increase in

p^* . The frequency of breakup was zero when $p^* \leq 0.55$ and increased up to 100 % when $p^* \geq 6.34$. This figure shows that the possibility of breakup of a bubble could be predicted by the value of p^* .

Breakup location

Figure 6 shows typical breakup locations of a single bubble for pressure difference $\Delta p = 9.26$ kPa. It is clear that the breakup location was scattered

Fig. 4. Sequence of deformation and breakup of single bubble. $Q_w = 13.1$ l/min, $\Delta p = 1.81$ kPa, and $r = 1.6$ mm.

Fig. 5. Breakup frequency of a bubble versus p^* .

However, most of the bubbles broke up at a region centered at $x/D=1.75$. It was observed that the trajectory of the bubble shift toward the centerline of the pipe. This condition may caused by imperfect position of the nozzle. The nozzle was not perfectly inline with the pipe centerline.

Slip velocity

Figure 7 shows positions of a bubble obtained for each frame. The solid line shows mean water velocity. Time and position were set zero at the bottom of the orifice. The mean water velocity was calculated based on orifice hole area, so it was indicated a maximum mean velocity. It is clear that the bubble velocity is slightly larger than water velocity. This means that slip velocity between bubble and water exists.

The effect of slip velocity on the development of the protrusion was also found to be similar to that of the pressure gradient (Mitchell and Hammitt, 1973). However at this stage of our work it is hard to distinguish the effects of slip velocity from the effects of pressure gradient on formation of protrusion.

Conclusion

The behavior of single bubble undergoing steep pressure gradient have been observed and visualized. It was found that an inward protrusion toward the downstream direction formed in a bubble just before the bubble broke up. The breakup frequency was sensitive to pressure gradient and bubble size. It was shown that the possibility of breakup of the bubble could be predicted by non-dimensional pressure gradient p^* . Breakup locations of single bubble were scattered and being independent of pressure gradient and bubble size. It was found that the bubble velocity was slightly larger than the water velocity.

References

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Fig. 6. Breakup location of single bubble for $\Delta p = 9.26$ kPa ($Q_w = 31.7$ l/min).

Fig. 7. Time again positions of bubble compared with calculated water position.