VISUALIZATION STUDY ON TRANSIENT LIQUID FILM BEHAVIOR AND INNER GAS FLOW AFTER RUPTURE OF A SOAP BUBBLE

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Summary The transient behaviour of liquid film and flow of inner gas were investigated in this paper. After rupturing of soap bubble, inner gas flew out to the outside through the hole of crack. This is called the primary flow. The removal velocity of upper liquid film was faster than that of bottom liquid film. The vortex was generated at the upper boundary and bottom boundary of liquid film. The secondary flow was generated due to momentum change after impinging soap film into a point, and it was faster than the primary flow.

INTRODUCTION

The flow induced by bubble collapse has been investigated for a long time to understand the cavitation phenomena and transient behavior of liquid film associated with surface tension and flow instability. There are many engineering applications such as the surface cleaning, metal hardening and flame extinguishment etc. [1-4]. Experimental studies of the behavior of soap bubbles rupturing by using high speed photography have been reported. Most of them have provided only the qualitative flow characteristics due to the limitation of the recording devices. The pressure inside the soap bubble is known to be $\triangle p = 4\sigma/R_{max}$ higher than the surrounding atmosphere, where σ is the surface tension of the soap film, and R_{max} is the radius of the soap bubble [5]. In addition, soap bubbles can be easily generated to the size fit for the experiments. The effects of surface tension and the pressure gradient to the bubble collapse flow can be clearly manifested. In this study, we aim to visualize the transient behavior of the liquid film and inner gas flow after rupture of a soap bubble using the high-speed camera. With the time-resolved images, various quantitative data such as inner gas velocity field, liquid film behavior and interactions between liquid film and internal flow were extracted and analyzed.

EXPERIMENTAL SETUP

Fig. 1 shows the schematic of experimental setup. A copper pipe with the diameter of 5 mm was dipped in liquid soap to generate soap bubbles. To measure velocity field of inner gas of the soap bubble, olive oil particles having 1-2 microns generated by Laskine nozzles were injected through the copper pipe and a soap bubble was generated. A continuous-wave laser of 532nm light source was installed and a sheet laser beam was made using the spherical lens and cylindrical lens. The frame rate of the high-speed camera (Photron Fastcam SA1.1) was set as 3600 fps and focused on the centre plane of the soap bubble. In order to provide contactless bubble rupture, a pulse laser (Mini-YAG pulse laser) was used and synchronized with the PIV system. Time resolved velocity fields were acquired by cross-correlation based PIV interrogations.

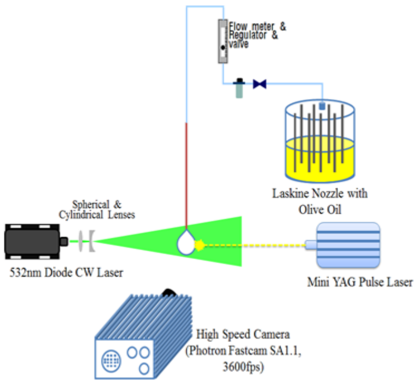

Fig. 1 Schematic of experimental setup

RESULTS AND DISCUSSION

Fig. 2 shows the transient behaviour of liquid film and inner gas flow after the soap bubble was ruptured. The initial size of the soap bubble was about 60 mm and hung on the pipe as shown in Fig. 2. The target point of the pulse laser was right hand side of the bubble which is 90 degree from the soap holder. From 0 ms to 15 ms, liquid film was removed. At 15 ms, liquid film impinges at a point and abruptly changes their momentum into orthogonal direction. It is clear to observe jetting phenomenon of soap liquid (bright image) in Fig. 2 (d). At first, internal gas moves right hand side through the hole made by the pulse laser due to pressure difference by surface tension. It is found that a series of the Kelvin-Helmholtz vortices, which arise in shear flow along a contact discontinuity, are formed around the bubble sphere. This is called the primary flow. The starting point of liquid film ruptured was the center of the right hand side of the sphere, but the impinging point of liquid film was below the center of the left hand side of the bubble. It means the upper film velocity is faster than that of lower film due to gravity. The bursting velocity is not a constant, but varies with the thickness of the soap film. It should be noted that Kelvin-Helmholtz vortices gets bigger after the soap film is completely removed. From Fig. 2(e) to (h), we can observe the secondary flow of inner gas due to the jetting motion of the soap liquid after impingement. Fig. 3 depicts velocity vector fields of inner gas flow just after the impingement of soap liquid film. It is obvious that the secondary flow has higher velocity compared to the primary flow. The direction of the secondary flow is not horizontal but diagonally upward toward the right side. This direction is perpendicular to the impingement direction which reflects the momentum change in direction. Since the secondary flow resembles a jet flow, so that another roll-up vortices are formed near the edge of the jet. As time goes on, the primary flow moves continuously to the right direction and inner gas moves uniformly with constant velocity. However, the secondary flow penetrates the inner gas media and push the total volume of gas toward the initial rupturing position.

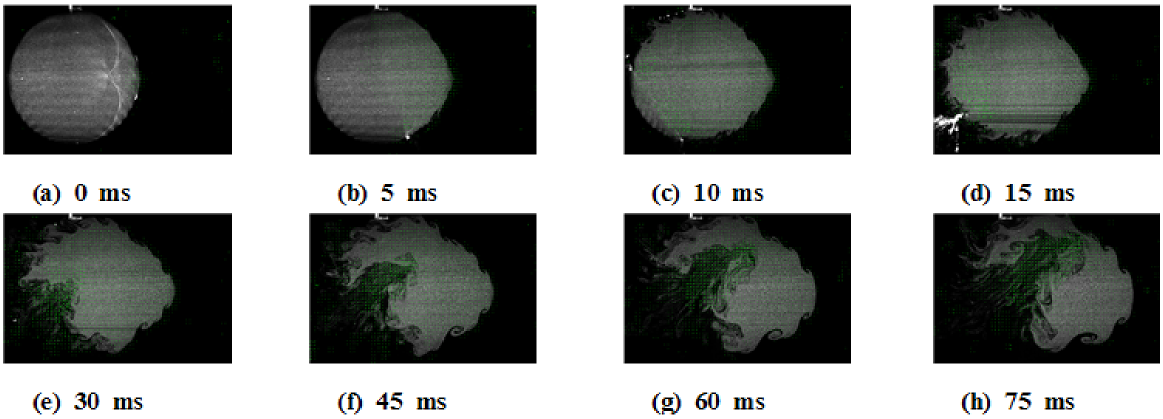

Fig. 2 Visualization of velocity field on transient behaviour of liquid film and inner gas flow

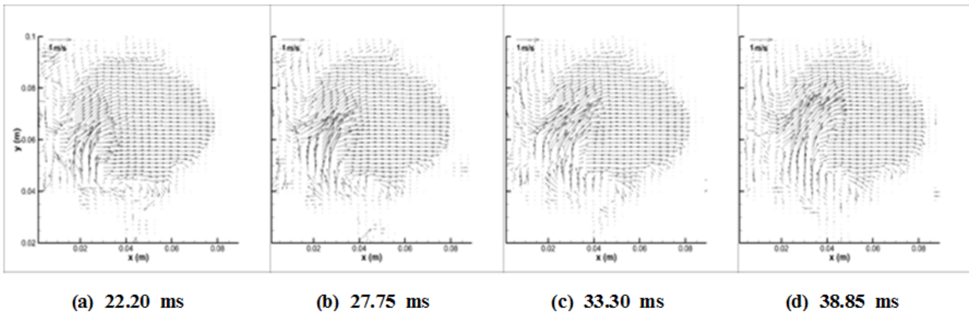

Fig. 3 Visualization of velocity vector field of inner gas flow

CONCLUSIONS

Quantitative visualization study has been conducted to understand transient behaviour of soap bubble rupturing by using the high speed time resolved PIV method. Contactless rupture was possible by the pulse laser. The removal velocity of upper liquid film was faster than that of bottom liquid film since upper side of film is thinner due to gravity. The different removal velocity creates different size of Kelvin-Helmholtz vortices. The primary flow moves continuously toward the direction of the rupture point. However, the secondary flow which generated by the momentum change after impingement of soap film was faster than the primary flow. The jet-like secondary flow moves perpendicular to the impingement position and penetrates inner gas volume abruptly.

References

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