Formation and Breakup of Ligaments from a Rotary Bell Cup Atomizer

M. Shirota[1*], Y. Hatayama[1], T. Haneda[1], T. Inamura[1], M. Daikoku[2], Y. Saito[3], H. Aoki[3]

1. Course of Intelligent Machines and Engineering, Graduate School of Science and Technology, Hirosaki University, Hirosaki, Aomori, Japan
2. Department of Mechanical Engineering, Faculty of Engineering, Hachinohe Institute of Technology, Hachinohe, Aomori, Japan
3. Department of Chemical Engineering, Graduate School of Engineering, Tohoku University, Sendai, Miyagi, Japan

Abstract

Rotary bell cup atomizer is commonly used in industrial spray painting for automobiles. In a rotary bell cup atomizer, liquid is spread on an inner bell-shaped surface of the rotating cup due to centrifugal force caused by a high rotational speed. The thinned liquid film is then split over the grooves at the peripheral edge of bell cup. Over a certain rotational speed of cup, ligaments are formed from the peripheral edge. The ligaments are further elongated and finally collapsed into droplets.

In the present study, we experimentally investigated the formation and breakup of ligaments ejected from a high-speed rotary bell cup atomizer. The rotational speed of bell cup was varied in the range between 5000 to 30000 rpm, while volumetric liquid supply rate was kept constant at 300 mL/min. We used glycerol aqueous solutions with viscosity of 30, 70 and 130 mPa·s. The elongated shape and breakup behavior of the ligaments were observed by using short exposure photography with a 180 nsec flash light. By using image processing based on edge detection and curve fitting, we quantitatively evaluate the following geometric properties of ligaments: trajectory of centerline, local curvature corresponding to the diameter of circular cross section and length of ligaments. Figure 1 and 2 show a typical examples of the local curvature and change in ligament diameter along its axis obtained through the image processing. The droplet size distributions were measured by using a particle size analyzer based on Fraunhofer diffraction theory. The uncertainty of photographic measurements was found to be 5 μm, the main factor of which arose from the optical resolution of the photography. In addition, a theoretical model on the droplet formation from a rotary atomizer with grooves at the edge is proposed and evaluated with experimental results. This theoretical model includes film thinning due to centrifugal force, film split over grooves at bell cup edge, ligament root formation at bell cup edge, and stretch and breakup of ligament.

The conclusions are summarized as follows: (1)The film spread on the inner surface of the bell cup is split over the groove at the edge of the cup when the thickness of the film is smaller than the depth of the groove. (2) The diameter of ligament at bell cup edge is determined by the width of the split film. (3)Simple momentum balance equating the momentum fluxes at the bell cup edge and some position downstream where the velocity profile flattens provide good estimation on the thinning rate of ligament diameter along its axis. In the analysis of momentum balance, we examined the effect of axial surface tension, Young-Laplace over pressure due to curved interface of ligament, centrifugal force, and viscous dissipation due to stretching. (4) Weber's theory on the breakup of viscous ligament gives good estimation on the diameter of droplet of liquids having Ohnesorge number ranging from about 1 to 5.

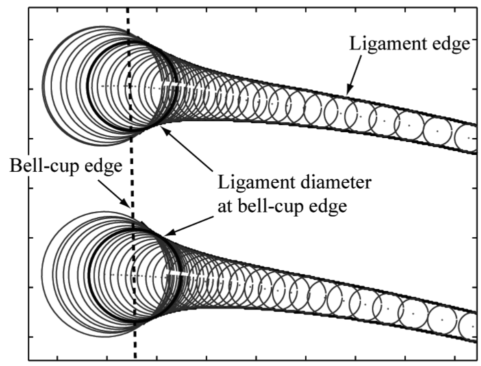

Fig. 1 Local ligament curvature obtained via image processing.

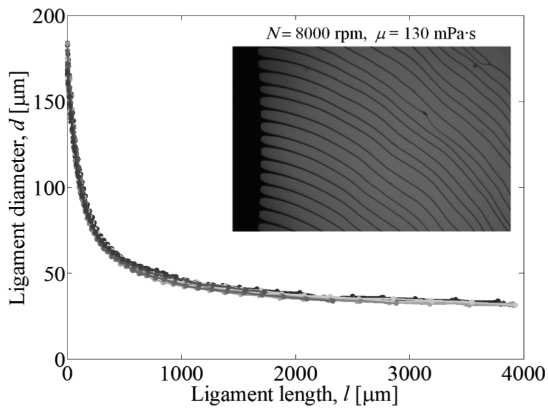

Fig. 2 Change in ligament diameter along its axis.

* Corresponding author: mshirota@cc.hirosaki-u.ac.jp