Droplet Size and Velocity Measurement in a 2×2 Sub-channel for the Reflood Heat Transfer Experiment

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1. Introduction

During the reflood phase of a postulated loss of coolant accident in a nuclear reactor, the liquid droplets can be generated by the entrainment at a quench front of a reflooding water. It is widely recognized that the behavior of the entrained droplet crucially enhances the reflood heat transfer by decreasing the superheated steam temperature and interacting with a rod bundle and spacer grids. For this reason, various experimental and numerical studies have been performed to predict the droplet behavior such as the droplet size, velocity, droplet fraction, etc.

An experiment about the droplet behavior inside a heated rod bundle is planned in a bid to investigate the interaction between the droplets and spacer grids. A 6×6 rod bundle test facility in Korea Atomic Energy Research Institute will be used for the experiment and a droplet injector will be utilized instead of simulating a quench front of a reflooding water in the experiment. The major measuring parameters of the experiment are the droplet size, droplet velocity, droplet frequency, droplet fraction, superheated steam temperature and so on. For the experiments, meanwhile, some basic techniques for the droplet behavior measurement and the droplet generation should be set up in advance.

In the present study, the droplet size and velocity measurement method was described. The application test result for the method, moreover, was introduced which was performed in a 2×2 reflood heat transfer test facility.

2. Droplet Size Measurement

An image processing technique was selected for the droplet size and velocity measurement considering the applicability of the measuring instrument to the test sections, 2×2 and 6×6 rod arrays. A high speed camera of which minimum shutter speed is 1/5μs and maximum frame rate is 5000/s with 512×512 image resolution was equipped for the measurement.

Fig.1 shows the procedure of the image processing for the droplet size measurement. Fig.1-(a) is the original image and Fig.1-(b) the filtered image with sobel filter and median filter. After that, the filtered image was binarized by Otsu's method [1] (Fig.1-(c)). To remove the defocused droplet from the images, the intensity profile across the boundary of a droplet was examined as shown in Fig. 1-(d). If the slope of the normalized intensity profile is less than a criterion, the droplet is regarded as defocused. After eliminating the defocused droplets, properties of each droplet such as the centroid, equivalent diameter, eccentricity, etc can be calculated. Fig. 2 shows the application result of the measurement method using micro-balls and dot patterns. Under the condition that various sizes of particles coexist from a few tens to several hundreds micrometer, the maximum measurement error was 6% and 1.8% with the particles smaller than 200 μm and larger than 200 μm respectively.

3. Droplet Velocity Measurement

Two-dimensional velocity of a droplet can be calculated from the two consecutive images by dividing the centroid displacement of a droplet in the two images by the time difference of the images. In the present tests, the time difference between two images were 1/5000 s and in the case that the height of the field of view is 5 mm, it is sufficient to measure the droplet velocity lower than 25 m/s.

The size and eccentricity of a droplet were used to figure out two matching droplets in the two images. It is likely to happen occasionally that more than two droplets in the second image have similar size and eccentricity with a droplet in the first image, so that it is difficult to find a pair of matching droplets simply from those topological information of the droplets. In that case, the match probability method developed by Baek and Lee was utilized [2]. Fig. 3 shows a typical example of the velocity measurement.

4. Application Test Result in a 2×2 Sub-channel

2×2 rod array test facility was constructed to visualize the reflood heat transfer phenomena. It has 4 electrical heaters inside a square channel. The diameter of the heater and the pitch between two heater rods were enlarged to 20 mm and 27 mm respectively, which is definitely advantageous for the visualization purpose. The heaters have uniform power distribution along the elevation and 1.8 m height. The test was performed to evaluate the applicability of the measuring method and the experimental condition is summarized in Table 1.

When a dispersed flow was observed inside the sub-channel, 8000 images were taken for 80 seconds with the high speed camera to measure the droplet size and velocity. The images were taken upstream and downstream of a grid spacer. Fig. 4. shows the measurement results of the droplet size and velocity.

As can be seen in the figures, about 2500 droplets were sampled from the images and the measured distributions of the droplet diameter and velocity appeared to be reasonable. From this application test result, it was concluded that the present measurement method is applicable for the droplet size and velocity measurement tests.

5. Conclusion

In the present paper, an imaging processing technique for the measurement of the size and velocity of droplets is introduced, which is supposed to be applied to a droplet behavior measurement test. The applicability of the technique was tested in 2×2 reflood heat transfer test facility and the result showed the good performance of the suggested measuring technique.

Acknowledgements

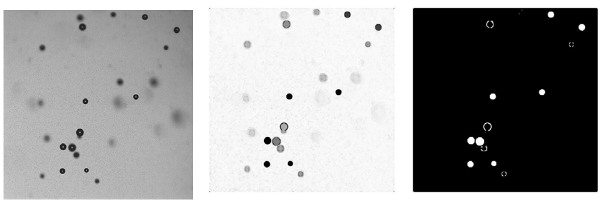
This study has been carried out under the nuclear R&D program by the Korean Ministry of Education, Science and Technology.

References

[1] N. Otsu , A Threshold Selection Method from Gray-level Histograms". IEEE Trans. Sys., Man., Cyber. 9: 62-66,1979.
[2] S.J. Baek and S.J. Lee, New Two-frame Particle Tracking Algorithm Using Match Probability, Exp. Fluids, Vol.22, pp.23~32. , 1996

Table 1. Test Condition

Reflood vel.	0.7 m/s	Power	2 kW
Max. cladding temp.	500°C	Cladding temp. at the measurement elevation	430°C



(a) Original image (b) Filtered image (c) Binarized image

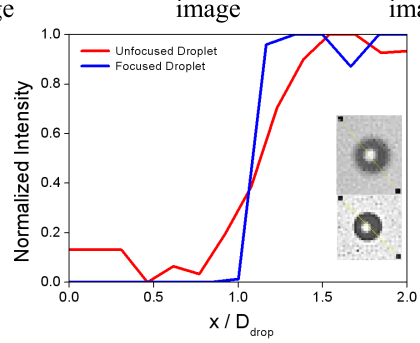


Fig. 1 Image processing procedure

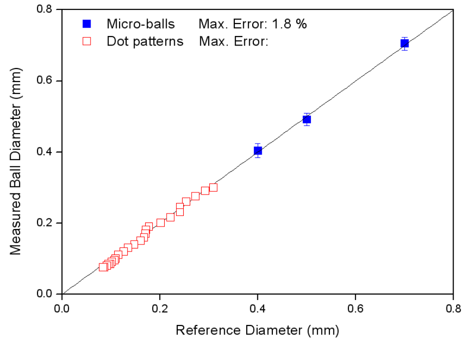
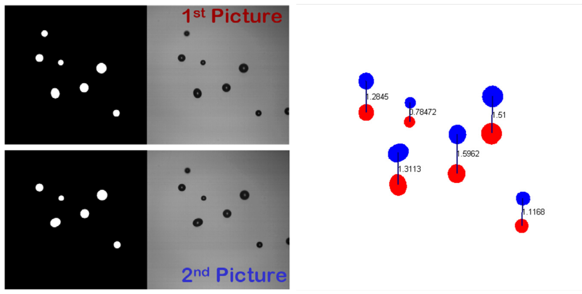
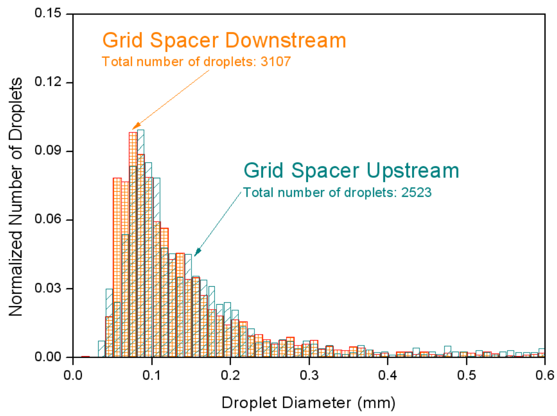


Fig. 2 Application test for the droplet size measurement method

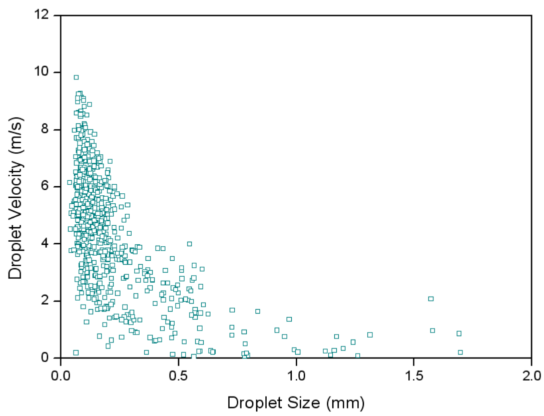


(a) Original images (b) Calculated velocity

Fig. 3 Example of velocity measurement



(a) Droplet size



(b) Droplet velocity

Fig. 4 2×2 test result