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Droplet Measurement in a 6×6 Rod Bundle Geometry for a Reflood Heat Transfer Test

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1. Introduction

During the reflood phase of a postulated loss of coolant accident in a nuclear reactor, the entrainment of liquid droplets can occur at a quench front of reflooding water. It is widely recognized that the behavior of the entrained droplet crucially affects the reflood heat transfer phenomena by decreasing the superheated steam temperature and interacting with a rod bundle and spacer grids. In this study, an experiment on the droplet behavior inside a heated rod bundle has been performed. The experiment was focused on the break-up of droplets induced by a spacer grid in a rod bundle geometry, which results in the increase of the interfacial heat transfer between droplets and superheated steam.

The present paper describes the 6×6 rod bundle test facility, ATHER (facility for Advanced Thermal Hydraulic Evaluation of Reflood phenomena). A digital image processing technique has been employed to measure the droplet diameter and velocity, and it is briefly introduced in this paper. Finally, some of the experimental data of the droplet behavior tests performed in the ATHER facility is presented and the mechanism of the droplet break-up is explained based on the visual observation result.

2. Test Facility and Measurement Method

A schematic diagram of the 6x6 reflood test facility, ATHER is indicated in Fig. 1. The test facility was fabricated for the reflood heat transfer experiment so that water used to be supplied from the bottom of the test facility. For the present droplet behavior test, however, the facility was modified so as to provide a steam flow and inject droplets directly into the test section instead of simulating a quench front of reflooding water. With this feature, steady-state tests were performed focusing on the interaction between droplets and a grid spacer.

An image processing technique was selected for the droplet size and velocity measurement in consideration of the applicability to the test sections, i.e. the 6×6 rod arrays. A high-speed camera was equipped for the measurement. A total of 4000 (2000 pairs) images were taken using the high-speed camera for every test, and the images were analyzed by image-processing software automatically. The details of the image processing method were described in our previous paper [1].

3. Experimental Results

The test matrix of the present experiment is listed in Table 1. The experiments were performed with various steam and droplet flow rates, droplet nozzle diameters, and maximum heater surface temperatures. Fig. 2 shows the typical example of the temperature measurement results of the heater rod and steam temperatures (Q40T700L20D1). Fig. 3 shows the normalized droplet numbers measured in the tests Q40T700L20D1 and Q40T700L15D2. These figures show the change of the droplet size distributions caused by a grid spacer and mixing vanes. The number of small droplets is increased significantly downstream of the grid spacer by the droplet break-up. However, it should be noted that the droplet size distributions downstream of the grid spacer do not have significant dependency on the impacting droplet sizes. Even if the impacting droplet size of the test Q40T700L20D1 is twice larger than the other test, the most frequent droplet sizes were found to be same with each other. This result is not consistent with the droplet break-up model [2] which was implemented into COBRA-TF as shown in Fig 3. According to this model, the most frequent droplet size is supposed to have strong relation with the size of impacting droplets.

This discrepancy was examined through the visual observation of the droplet behavior around the grid spacer and the mixing vanes. The droplet break-up phenomena are indicated in Fig.4-(a) under the experimental conditions reported in this paper. It was observed that the mixing vane and the grid spacer were covered by a liquid film, and then droplets were generated from the tearing off of the liquid film at the end of the mixing vane. The droplets entrained from the liquid film had large diameters (hundreds of micrometer), but they were broken up into small droplets by a hydrodynamic break-up such as the bag-type break-up and the shear break-up [3]. In brief, the droplet break-up occurs by means of a two-step process if the grid spacer is rewetted: the droplet entrainment from the liquid film on the grid spacer and then the hydrodynamic break-up. This mechanism, however, has not been considered as a droplet break-up mechanism in the previous studies. In order to investigate the droplet break-up phenomena on a dry mixing vane, an additional visualization test (Q30T600L03D3) was carried out with a lower droplet flow rate. As shown in Fig. 4-(b), the shattering of a droplet on a dry mixing vane was clearly observed. From this visual observation, it was inferred that the previous droplet break-up model is incapable of predicting the change in the droplet diameter caused by a grid spacer when the grid is rewetted by droplets and covered by liquid film. This result is agreed with the conclusion of Bajorek and Cheung [4] published recently. In a future study, the droplet diameter change induced by a wet grid will be investigated further, and then a model which can describe the mechanism will be proposed for nuclear reactor system analysis codes such as SPACE and MARS.

4. Conclusion

In the present paper, the droplet behavior inside a 6×6 rod array was investigated for the droplet break-up phenomena caused by a grid spacer and mixing vanes during the reflood phase of an LBLOCA. A series of experiments were performed with various droplet injection diameters, and steam and droplet flow rates. The interaction between droplets and a grid spacer was visualized, and the velocity and size of droplets were measured using an imaging processing technique with a high-speed camera. The visual observation results showed that the droplet break-up occurs by means of a two-step process: the droplet entrainment from the liquid film and then the hydrodynamic break-up into small droplets. In future studies, the droplet break-up mechanism with a wet grid will be investigated further, and a model which can describe the mechanism will be proposed.

References

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Acknowledgments

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Table 1 Test matrix

Test Number	$\dot{m}_{steam}$ (g/s)	T_{max} (°C)	$\dot{m}_{drop}$ (g/min) /D_{nozzle} (mm)	Test Number	$\dot{m}_{steam}$ (g/s)	T_{max} (°C)	$\dot{m}_{drop}$ (g/min) /D_{nozzle} (mm)
Q60T450L20 D1	60	450	20 / 0.45	Q60T500L20 D2	60	500	20 / 0.25
Q40T600L20 D1	40	600	20 / 0.45	Q40T500L08 D2	40	500	8/0.254
Q40T500L20 D1	40	500	20 / 0.45	Q40T700L15 D2	40	700	15/0.254
Q40T700L20 D1	40	700	20 / 0.45	Q40T500L15 D2	40	500	15/0.254
Q40T700L40 D1	40	700	40 / 0.45	Q50T600L15 D2	50	600	15/0.254
Q90T500L20D2	90	500	20 / 0.25	Q25T600L15 D2	25	600	15/0.254
Q60T500L20 D2	60	500	20 / 0.25	Q15T600L15 D2	15	600	15/0.254
Q40T500L08 D2	40	500	8/0.254	Q30T600L03 D3	30	600	3/0.125

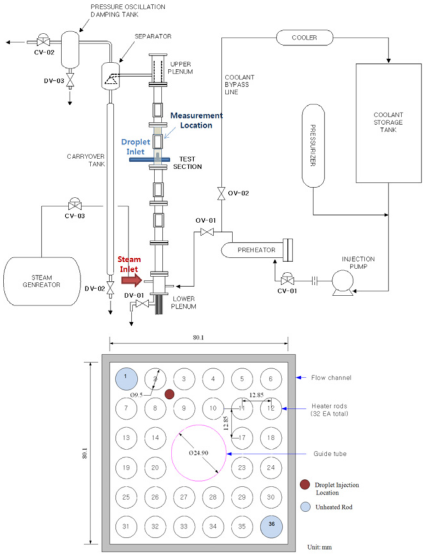


Fig. 1 ATHER test facility

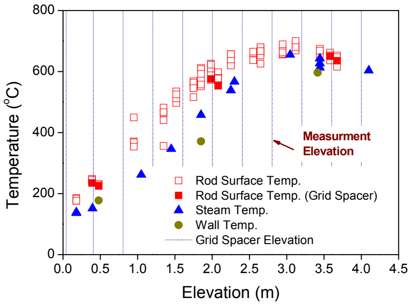


Fig. 2 Temperature measurement result

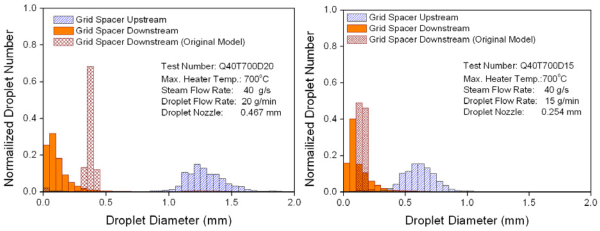
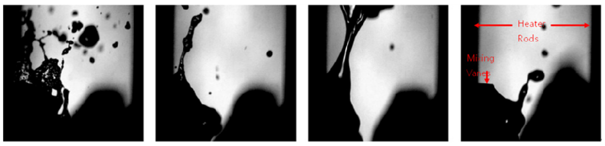
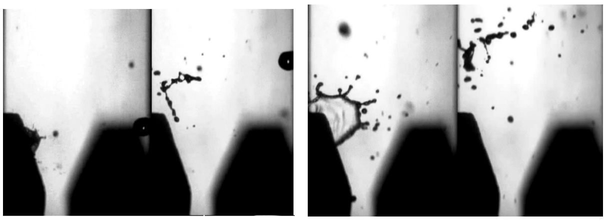


Fig. 3 Droplet size distribution (test vs. model)



(a) Test-Q40T700L15D2 (Wet Grid)



(b) Test-Q30T600L03D3 (Dry Grid)

Fig. 4 Visualization of droplet break-up on a mixing cane