Droplet Measurement Across a Grid Spacer in a 2×2 Rods During Reflood

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1. Introduction

Spacer grids are the essential structures used in nuclear fuel rod assemblies to maintain a constant distance between fuel rods. The droplet behavior across a spacer grid has received a great attention because droplets reduce significantly the temperature of fuel rods during the reflood in a postulated loss of coolant accident.

The present study presents preliminary results for the droplet breakup during reflood. Measurements were made of droplets across a spacer grid in a rectangular channel with 2×2 electrically-heating rods. The sizes and velocities of droplets were measured by the help of image processing. The experimental data was statistically analyzed and compared with an existing correlation, in order to confirm the validity of the present experiment.

2. Experimental Method

Figure 1 depicts a schematic diagram of a test section for reflood experiments. The heating length of the rods is 1800mm. A measurement window, made of Pyrex glass, is placed at the middle location of the test section. The rods are heated with uniform power in the axial direction. Five spacer grids having mixing-swirl vanes are installed in the test section. One grid is positioned at the measurement window location. Two measurement regions are placed about 5cm above and below the spacer grid, respectively.

Figure 2 shows a cross-sectional view 2×2 rods and a close-up photo of the spacer grid. The blockage ratio of the grid is calculated about 0.18. The hydraulic diameter is about twice as large as the hydraulic diameter of a typical rod bundle in PWR. Thus, the present test channel might not simulate actual phenomena during the reflood because the droplet diameter could be affected by the steam velocity. For this reason, the experimental data were compared with the correlation using the parameters relating to upcoming droplet. The experiment was performed at two conditions depending on the initial temperature of the rods: $T_{w,initial}$=500, 700℃. The velocity and the temperature of reflooding water were $v_{reflood}$=1.0cm/s, $T_{reflood}$=40℃, respectively. The heating power is 0.4kW/rod,

A xenon lamp was used to illuminate droplets. Droplet images were recorded by a high-speed camera (Redlake MotionXtra HG-100K).

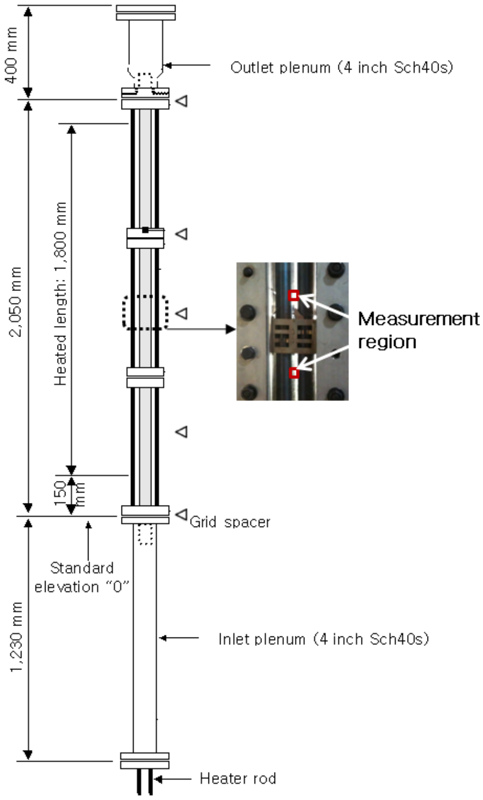

Fig. 1. Schematic diagram of a test section

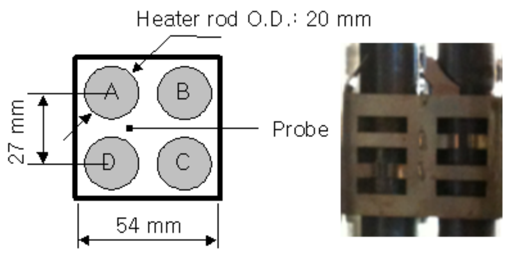

Fig. 2. 2×2 heater rods and spacer grid

3. Results and Discussion

Tables 1 and 2 show the results for two cases The analysis was performed for every 10 seconds. It would be better to reduce the time period for transient analysis. However, short time periods result in the small number of droplets. We found that 10 seconds was reasonable for the present experimental data, which included hundreds of droplets. It is observed that the droplet diameter increases as time lapses.

Table 1. Results for $T_{w,initial}$=500℃

time	upstream		downstream	
[s]	D_{32}[μm]	v_{mean}[m/s]	D_{32}[μm]	v_{mean}[m/s]
0~10	-	-	-	-
10~20	510	4.5	456	3.9
20~30	748	4.5	556	4.2
30~40	1173	6.8	856	5.0

Table 2. Results for $T_{w,initial}$=700℃

time	upstream		downstream	
[s]	D_{32}[μm]	v_{mean}[m/s]	D_{32}[μm]	v_{mean}[m/s]
0~10	-	-	-	-
10~20	466	5.4	456	4.2
20~30	1031	4.9	930	4.3

Cheng and Bajorek (2010) proposed a correlation for predicting the droplet diameter behind a dry spacer grid. This correlations is adopted for comparison with the present experiment since it does not include any information about the steam.

$$\frac{d_{32,downstream}}{d_0} = \left(1 + 0.1803\varepsilon We_0^{0.558}\right)^{-1} \tag{1}$$

Here, $d_{32,\mathrm{downstream}}$ and d_0 denote the Sauter mean diameter of the outgoing droplets and the diameter of the upcoming droplet. Equation (1) uses the assumption that the upcoming droplets have a uniform size, and it is applicable to a dry spacer grid in dispersed droplet flow. In this study, d_0 is replaced by the Sauter mean diameter of the upcoming droplets, as Cheng and Bajorek (2010) did. The symbol ε represents the fraction of upcoming droplets undergoing breakup, which is not the exactly same as the blockage ratio, but closely related to the blockage ratio. The We_0 is the Weber number relating to droplets.

$$We_0 = \frac{\rho_d v_d^2 d_0}{\sigma_d} \tag{2}$$

Figure 3 compares the present data with the model proposed by Cheng and Bajorek (2010). Sugimoto and Murao (1984) reported that the breakup ratio was 0.89~0.97 for a dry grid. As can be seen in Fig. 3, the experimental values are similar to the values of Sugimoto and Murao (1984). The value of ε=0.05 provides a qualitative agreement with the present data, which is much less than the blockage ratio 0.18 of the present grid. The value of ε=0.05 underpredicts the breakup ratio. This difference can be explained by two reasons. One is the exclusive applicability of the correlation to a dry grid. At the initial stage, the present grid is dry, however, the grid gets wetted with the lapse of time. The other is that ε is not the same as the blockage ratio. The blockage ratio is based on the projected area of the grid. However, since the steam flows according to the direction of mixing-vanes, ε could be less than the blockage ratio. Cheng and Bajorek (2010) states that ε=0.362 and ε=0.15 are need to match the RBHT data and Yao et al. (1988) data.

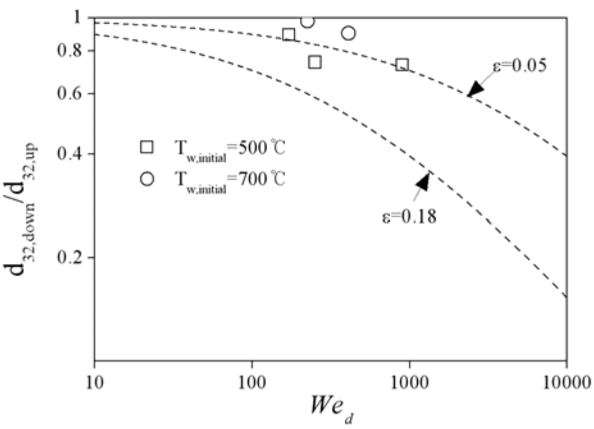

Fig. 3. Comparison with the previous correlation by Cheng and Bajorek (2010)

4. Conclusion

Measurements have been made of droplets generated during the reflood. The sizes and velocities were measured upstream and downstream of the spacer grid. It was found that the upcoming droplets break into smaller droplet. The experimental results lie within the predictable range of the existing correlation using the Weber number relating to droplets. By adjusting the value of ε, the correlation could be fitted to the experimental data.

The present experiment however has some problems to be resolved. The stream velocity was not measured due to the limitation of the steam flow meter. The volume flow rate was too low in the early stage. For this reason, the interaction between steam and droplets was not investigated. The enlarged rods might not simulate actual reflood phenomena because the increased flow area reduces the steam velocity and changes the wall-to-fluid heat transfer. In addition, the measurement window was placed only about 1m above the bottom. The duration period for dispersed droplets was so short that transient analysis was limited.

Acknowledgments

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