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Deposition Rate of Droplets in a Horizontal Pipe

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1. Introduction

Deposition of droplets in a horizontal pipe is very important in the study of annular gas-liquid flow. During the reflood phase of LBLOCA, water carried over from the core is either deposited in the upper plenum, or carried over with the steam to the hot-legs and steam generators. The water carried over to the loops is deposited and accumulated in the hot-legs and steam generator inlet plenum. However, the water not deposited in the hot-legs is carried by the steam flow into the SG inlet plenum and U-tubes, which cause a steam binding problem.

The main goal of this work is to evaluate the deposition rate in the horizontal pipe simulating the hot-leg. We investigate the effects of droplet mass flux and the air velocity on the deposition rate.

2. Experiments and analysis

2.1 Experimental facility and test ranges

Figure 1 shows the schematic of experimental facility. To simulate the hot-leg, a horizontal pipe is used. The diameter of pipe is 0.084 m and the length is 0.5 m (Section 2). To measure the deposition rate, the flow rate of de-entrained liquid film is extracted at two points (positions A and B in Fig 1) along the pipe axial direction. To inject droplets into the test section, the test section is connected to the upper plenum of KAIST upper plenum test facility [1]. The distance of horizontal pipe from the multi-hole plate is 0.5 m.

When the droplets flow into the hot-leg, the flow direction is changed from vertical flow to horizontal flow, which results in the deposition of a significant amount of droplets at the pipe entrance. To minimize the effect of the radial velocity of droplets, the water deposited at pipe entrance (Section 1) is extracted at a distance of 15 cm from pipe entrance (position A) by a liquid film extraction device. To measure the deposition rate, the deposited water is extracted at a distance of 65 cm from pipe entrance (position B). The flow rate of droplets not deposited in Section B is measured at the end of pipe (Section 3). The inner diameters of Sections A and B are 0.1 m and 0.07 m, respectively. The gaps between the inner diameter of pipe and the outer diameter of film extraction device are 5 mm at position A and 4 mm at position B.

The ranges of droplet mass flux are 0.52 through 1.7 kg/m^2s and the ranges of air velocity in the pipe are 15 through 20 m/s.

2.2 Deposition rate and deposition rate constant

The deposition rates, R_D, are calculated by assuming that the deposition is similar to the molecular mass transfer as follows:

$$R_D = k_D \cdot \overline{C}\,, \qquad (1)$$

where k_D and $\overline{C}$ are the deposition rate constant and the mean droplet concentration over the flow channel, respectively. The mean droplet concentration can be calculated as follows [2]:

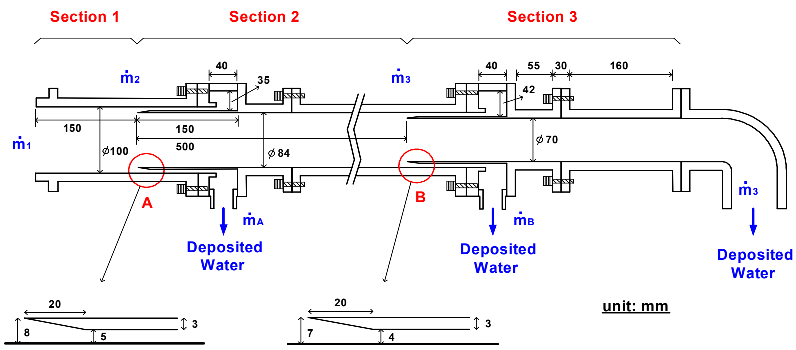

Fig. 1. Schematic of test facility.

$$\overline{C} = \frac{\dot{m}_d}{\frac{\dot{m}_a}{\rho_g}\frac{V_d}{V_a} + \frac{\dot{m}_d}{\rho_d}} \approx \rho_g \frac{\dot{m}_d}{\dot{m}_a}\frac{V_a}{V_d}. \quad (2)$$

The deposition rate can be calculated as follows:

$$R_D = \frac{\dot{m}_{de}}{A}, \quad (3)$$

where $\dot{m}_{de}$ is the mass flow rate of de-entrained water and A is the inner area of the pipe.

3. Results and Discussion

3.1 Effects of droplet mass flux and air velocity on the deposition rate

Figure 2 shows the effects of droplet mass flux and gas velocity on the deposition rate in the horizontal pipe. The result indicates that about 80% of droplets are deposited in Section 2 regardless of the droplet mass flux (0.52 - 1.7 kg/m2s) and air superficial velocity (15 - 20 m/s). The deposition rate increases as the inlet droplet mass flux ($G_{d,in}$) does and can be correlated by linear fitting as follows:

$$R_D = 0.333 \cdot G_{d,in}. \quad (4)$$

Assuming that the droplet velocity and the air velocity are the same, the mean droplet concentration calculated by Eq. (2) ranges from 0.034 to 0.085 kg/m^3. From the experimental data, the values of k_D range from 0.5 to 0.66 m/s.

3.2 Development of an empirical correlation

In this experiment, about 80% of droplets are deposited inside a pipe with a length of 0.5 m and a diameter of 0.084 m, regardless of droplet mass flux and air velocity. This result means that about 96% of droplets are deposited inside 1 m-long pipe with the same diameter. From this result, an empirical correlation is developed to evaluate the deposition efficiency in a horizontal pipe (η_H) as follows:

$$\eta_H = \frac{G_{de}}{G_{d,in}} = 1 - \exp\left[-\frac{(L/D)}{3.7}\right], \quad (5)$$

where G_{de} is the deposited droplet mass flux, $G_{d,in}$ is the inlet droplet mass flux, L is pipe length and D is the inner diameter of horizontal pipe. Figure 3 shows the comparison of the present data with the developed correlation.

4. Conclusions

- In a horizontal pipe with a length of 0.5 m and diameter of 0.084 m, about 80% of droplet mass flux is deposited regardless of droplet mass flux (0.52 - 1.7 kg/m^{2}s) and air velocity (15 - 20 m/s).
- The droplet deposition rate, R_D, linearly increases as the inlet droplet mass flux does.
- A correlation is developed to predict the deposition efficiency in the horizontal pipe.

REFERENCES

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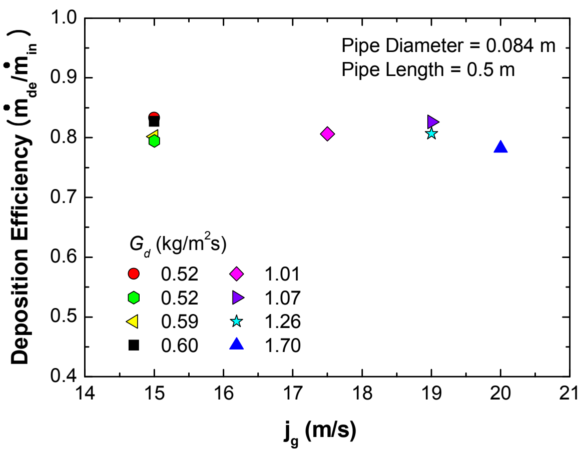

Fig. 2. Effects of droplet mass flux and air velocity on droplet deposition.

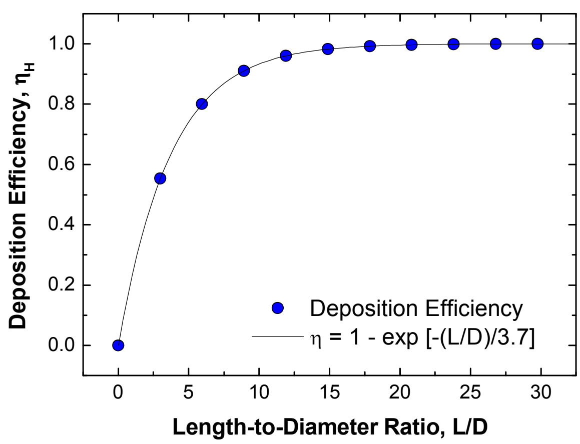

Fig. 3. Comparison of the present data with developed correlation.