Experimental Study on the Fluid Structure of Injected Vertical Falling Liquid Film Flow with the Horizontal Gas Flow for DVI

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1. Introduction

The purpose of this chapter is to study multi-dimensional behavior of the downcomer during the reflood period using. Unlike the multi-dimensional flow caused by countercurrent flow, the flow inside the downcomer is multi-dimensional due to drastic complex cross flow. However, No studies about cross two phase have been conducted. Thus, the concrete liquid film thickness, local gas velocity, and existing theoretical formulae for onset of entrainment model for conventional geometry were investigated.

2. Methods and Results

2.1 Experimental apparatus

An experimental apparatus, as shown in Fig. 3.1, was fabricated to experimentally simulate the liquid film flow movement and droplet entrainment of the hydraulic phenomena that appear inside the downcomer during the reflood period. The experimental device was designed to simulate the interactions of the abnormal cross flow of the horizontal steam discharged through the broken cold leg with the liquid film flow generated when the safety injection water is injected through the DVI pipe in the APR 1400 type downcomer structure. The experimental apparatus was designed by downscaling at 1/20 using a modified linear scale ratio for the downcomer structure. In this study, the thickness of the downcomer liquid film flow was measured using a confocal chromatic sensor (CCS) satisfying the aforementioned conditions for a high-precision experiment in order to determine the liquid film thickness in relation to the transmission of the interface momentum in the downcomer. The CCS, which is of the noncontact type, does not interfere with liquid and gas flows and can measure the thickness of liquid film flow with a measurement frequency of up to 2 kHz.

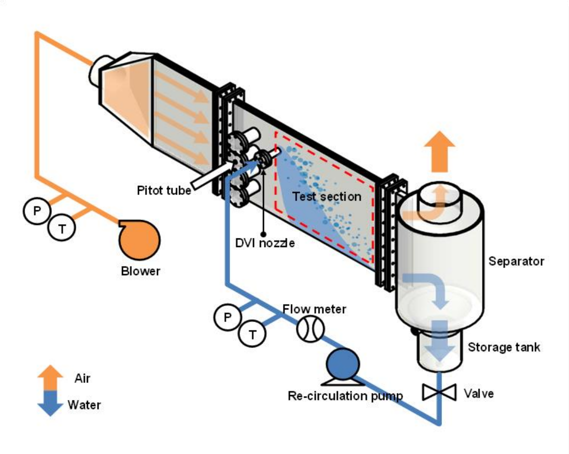

Fig.1 Schematic of experimental setup

2.2 Liquid film flow shift

The width of the liquid film flow is a critical parameter, because it is determined as the perimeter from the liquid film Reynolds number when there are almost no droplets and the lateral velocity vector of the flow is almost constant. The width and shift of the liquid film flow at different regions were measured with a 1/20 scaled down experimental downcomer apparatus (water: 0.29, 0.45, 0.59, 0.74 m/s, air: 0, 3.4, 4.9, 6, 6.9, 7.7, 8.5, 9.1, 9.8, 10.4, 11, 11.4, 12, 12.9, 13.4, 13.8, 14.2, 14.6, 15 m/s). Fig. 3.11 shows the results of the liquid film flow width experiment at the 1/20 scaled down experimental regions of the downcomer (water: 0.45 m/s, air: 0, 6, 8.5, 10.4, 12 m/s). The y-axis in Fig. 2 is the vertical axis of the test bed and the zero point is the nozzle position. The effects of the lateral airflow rate and nozzle injection speed on the shift of liquid film flow were examined.

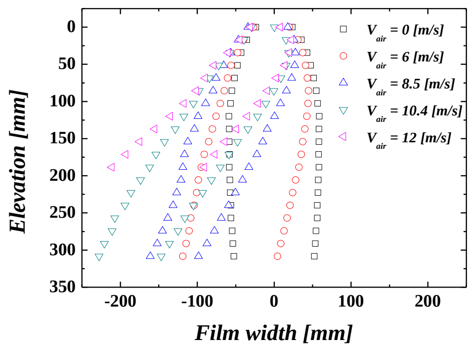

Fig. 2 Film width for 1/20 scale (water velocity :0.45m/s, air velocity:0, 6, 8.5, 10.4, 12m/s)

The shift of the liquid film flow was examined for the dimensionless liquid flow velocities of 0.9, 1.3, 1.8, and 2.2 and for the dimensionless airflow velocities of 0–1.63. The graph in Fig. 3 shows the relationship between the shift of the liquid film flow and the velocity of the dimensionless airflow. The dimensionless flow rate in this graph used the Wallis parameter used for water and air velocity in the figure, respectively. The flow rate of the injected liquid, shown in Fig. 3, does not have much effect on the liquid film shift, and the degree of shift was verified to be proportional to the square of the airflow rate.

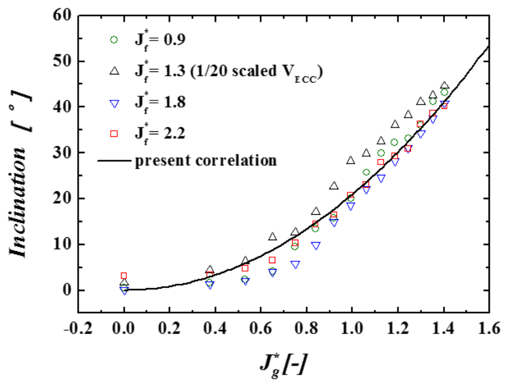

Fig. 3 Liquid film flow shift due to gas flow

2.3 Film thickness

Fig. 4 shows total trend of film flow based on the data. As a characteristic of cross two phase flow, mean film thickness and wave amplitude increase as air flow rate increases. On the other hand, base film thickness decreases in the trend of air increasing. The figure shows the graph of the amplitude of liquid film flow. The amplitude increased with an increase in the airflow rate. The amplitude was very large and the roll waves appeared at the liquid film flow that first met with air. The figure shows the effects of airflow rate on the amplitude of liquid film flow. The graph of the base thickness of the liquid film flow is shown in Fig. 4, which illustrates the effect of airflow rate on the base thickness. The base thickness decreased with an increase in the airflow rate. As a result, the mean thickness of liquid film decreased; however, there was an increase in the amplitude. The base thickness at the edge of the liquid film flow was larger than that at the other parts. Thus, the thickness condition of roll wave was already satisfied even in areas with a low airflow rate. The figure also shows the graph of the maximum thickness of liquid film flow. The maximum thickness increased with an increase in the airflow rate.

It is important that this is opposite results to the studies about the effect of gas velocity in annular flow. For the annular flow cases which air and water flow only as counter current flow or concurrent flow, wave amplitude and mean film thickness show inversely proportional trend to gas flow rate. The other case, complex cross flow, its finite film flow condition causes a rim region with large thickness. As this region critically affected by air flow, wave amplitude becomes large and total instability increases. Therefore, these phenomena make complex cross flow have lower onset of entrainment point than annular flow.

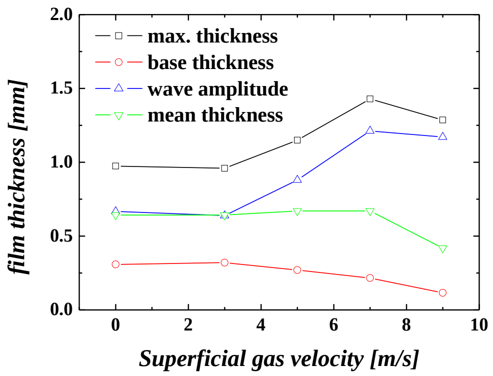

Fig. 3 Maximum film thickness, base film thickness, wave amplitude and mean film thickness when the liquid nozzle velocity is 0.45 m/s and the lateral gas velocity is 0 m/s, 3 m/s, 5 m/s, 7 m/s and 9 m/s.

3. Conclusions

To investigate the width, shift, and thickness of the liquid film flow and the wave characteristics in a downcomer structure, various measurement methods such as CCS, PIV, and shadowgraph were used. As a result, an experimental formula for the onset of droplet entrainment was proposed in this study.

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