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Validation of Friction Models in MARS-MultiD Module with Two-Phase Cross Flow Experiment

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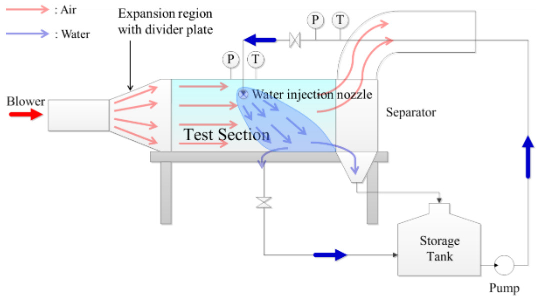
1. Introduction

The system analysis codes, for example, RELAP5/MOD3, MARS, SPACE, TRACE (U. S. NRC, 2007) and CATHARE3 adapted multidimensional modules to simulate the two-phase flow more accurately. However, these modules in computational codes should be validated with multidimensional experimental study. In the downcomer of Advanced Power Reactor 1400 (APR1400) which has direct vessel injection (DVI) lines as an emergency core cooling system, multidimensional two-phase flow may occur due to the Loss-of-Coolant-Accident (LOCA). The accurate prediction about that is high relevance to evaluation of the integrity of the reactor core. For this reason, Yang performed an experiment that was to investigate the two-dimensional film flow which simulated the two-phase cross flow in the upper downcomer, and obtained the local liquid film velocity and thickness data [1]. From these data, it could be possible to validate the multidimensional modules of system analysis codes. In this study, MARS-MultiD was used to simulate the Yang's experiment, and obtained the local variables. Then, the friction models used in MARS-MultiD were validated by comparing the two-phase flow experimental results with the calculated local variables.

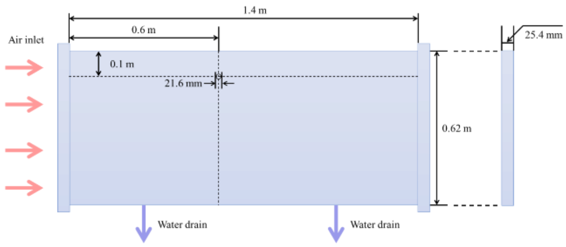
2. Two-phase cross flow experiment

2.1 Experimental facility and test conditions

An experimental facility was devised to measure the local film velocity and thickness of the two-dimensional film flow which used air and water as working fluids, as shown in Fig. 1-(a). The air was selected as a gas phase fluid instead of steam to separate condensation or heat transfer effect from the hydraulic effect. The test section was made as an unfolded-shaped upper downcomer with a 1/10 reduced scale of APR1400, as shown in Fig. 1-(b). The experimental facility includes a water supply system to simulate the falling liquid and an air supply system to provide transverse gas flow. The water which was injected through a nozzle impinged on one side of the test section and made a two-dimensional liquid film falling down the wall. The air was injected by a blower along the pipe, and uniformly distributed by a perforated plate in the expansion section. The injected air and falling water make a two-dimensional film flow. At the end of the test section, the two phases were separated by a separator. After that, the water returned to the storage tank through the drain line at the bottom of the test section and separator. The air exited through the top of the separator.



(a) Flow directions of working fluids



(b) Test section

Fig. 1. Schematics of experimental facility [1]

In order to define test conditions, the modified linear scaling method, which was developed by Yun et al. [2], was adopted. This model preserves Wallis parameter, as shown in Eq. (1), between model and proto type.

$$j_k^* = \frac{\dot{m}_k}{\rho_k A_{flow}}\left[\frac{\rho_k}{(\rho_f-\rho_g)gD_{gap}}\right]^{1/2} \qquad (1)$$

According to this scaling method, the liquid and gas velocities were divided by the square root of the scaled length ratio and the reduced velocities were employed as test conditions. In the prototype reactor, it is assumed that the emergency core coolant (ECC) injected at a 2 m/s liquid velocity through the DVI lines, and the velocity of later steam varied from 15 m/s to 45 m/s [3]. Following the modified linear scaling method, 0.63 m/s of inlet liquid velocity and 5~15 m/s of later air velocity were selected as experimental conditions.

2.2 Local measurement methods for two-dimensional film flow

2.2.1 Ultrasonic thickness gauge for local liquid film thickness measurement

The pulse-echo type ultrasonic thickness gauge was used to measure the liquid film thickness using the round-trip time of an ultrasonic wave. It is following as Eq. (2).

$$\delta_f = \frac{c_f(T)\Delta t}{2} \qquad (2)$$

where δ_f is the liquid film thickness, c_f is sound speed in water, T is the temperature of water, and Δt is the round trip time of an ultrasonic wave.

2.2.2 Depth-averaged PIV method for local liquid film velocity measurement

As shown in Fig. 2, two lasers excited the fluorescent particles in the liquid film and high speed camera took pictures of particles' movement in front of the test section. With the depth-averaged PIV method, it was possible to maintain the light intensity since it is not disturbed by the oscillation on the boundary nor attenuation of laser source because the light does not travel along the liquid film.

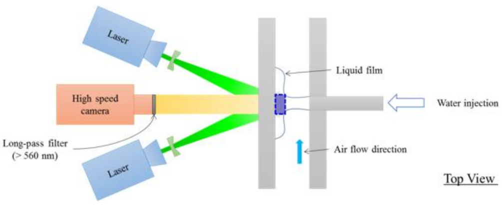
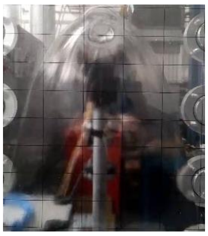


Fig. 2. Depth-averaged PIV method for measurement of liquid film velocity

2.3 Experimental results

Fig. 3 shows the change of the liquid film shape with increase of lateral air velocity. The experiment without air injection was considered as a reference case. The interaction between the falling liquid film and the lateral air induces momentum transfer through the interface. Fig. 4 shows the liquid film velocity and thickness according to the increase of lateral air velocity. The water inlet nozzle was positioned at (0 mm, 0 mm).

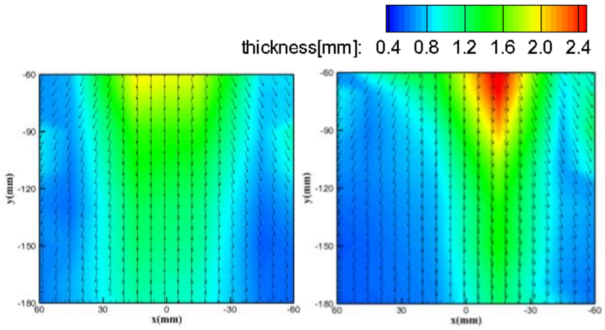


(a) 0 m/s

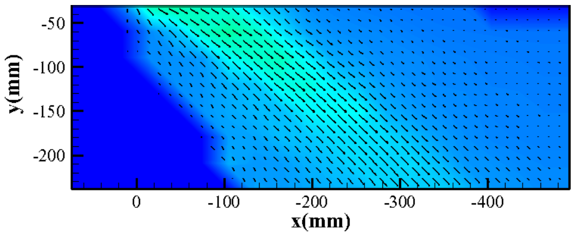
(b) 5 m/s

(c) 15 m/s

Fig. 3. Change of liquid film shape with increase of air velocity



(a) 0 m/s (b) 5 m/s



(c) 15 m/s

Fig. 4. Local liquid film velocity and thickness with increase of air velocity

3. MARS-MultiD calculation

3.1 MARS-MultiD modeling

The nodalization of test section for MARS-MultiD is presented in Fig. 5. The numbers of the volumes were 189 with 21 along the x-direction, and 9 along the y-direction. The water was injected into the center of the 89^{th} volume which was simulated as an impinging spot. The air was injected into the test section laterally with four different velocities (0 m/s, 5 m/s, 10.7 m/s, 15 m/s). The liquid film thickness could be calculated by the liquid fraction in each volume, and the liquid film velocity could be calculated in each junction connected with volumes.

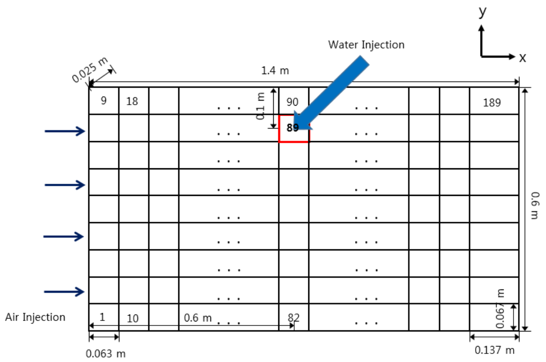
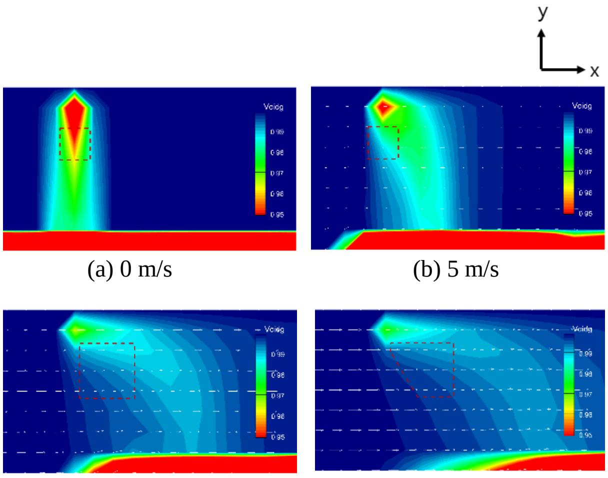


Fig. 5. Nodalization of the test section for MARS-MultiD simulation

3.2 Calculation results and analysis

The local variables such as the liquid film velocity and thickness could be obtained from MARS-MultiD calculation. Fig. 6 shows the liquid film thickness change with increase of lateral air velocity (Case-1). According to the increase of air velocity, the amount of liquid film moving toward the outlet side of the test section increased due to the two-phase interfacial effect.

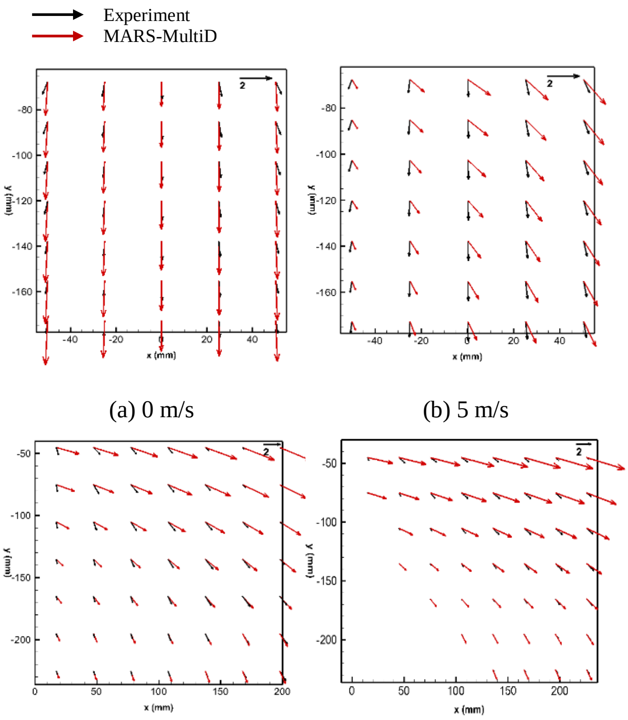


(a) 0 m/s (b) 5 m/s

(c) 10.7 m/s (d) 15 m/s

Fig. 6. Void fraction change with increase of air velocity (Case-1)

In order to validate the adequacy of MARS-MultiD calculation, the variables obtained from the calculation should be compared with the experimental results. As shown in Fig. 7, the local liquid film velocity vectors were compared with the experimental data at the marked region in Fig. 6 (Case-1). The reference case shows that the magnitude of the liquid film velocity calculated by the MARS-MultiD was overestimated compared with experimental data. In other cases with different lateral air velocities, the magnitude of the liquid film velocity was also much larger than those of experimental data. Not only the magnitude, but the direction of the liquid film velocity was different from experimental data. The calculated one was much more toward to the outlet side of the test section.

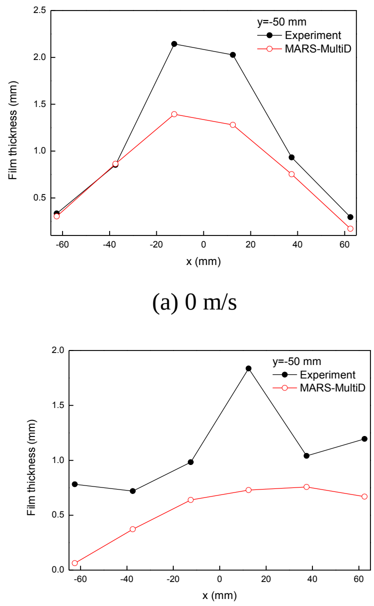


(a) 0 m/s (b) 5 m/s

(c) 10.7 m/s (d) 15 m/s

Fig. 7. Comparison of liquid film velocity (Case-2)

The variation of the local liquid film thickness on a horizontal line (from x=-62.5 mm to x=62.5 mm) at y=-50 mm is presented in Fig. 8 (Case-3). In both cases (0 m/s, 5 m/s), calculated liquid film thickness were underestimated than experimental data.



(a) 0 m/s

(b) 5 m/s

Fig. 8. Comparison of liquid film thickness (Case-3)

Consequently, the calculated results by the MARS-MultiD overestimated the magnitude of the liquid film velocity, and underestimated the liquid film thickness. Those results are qualitatively reasonable for mass conservation which can explain the reason that the faster liquid film is, the thinner it is at the same flow rate. The problem was that the MARS-MultiD could not estimate the effects of some frictions properly including wall friction and interfacial friction which play significant role to decide the liquid film flow. Especially, the effect of the wall friction that could be evaluated from the reference case should be increased to decrease the magnitude of liquid film velocity. The effect of the interfacial friction that could be evaluated from the cases with air injection should be decreased to follow the direction of liquid film velocity with experiment data. However, these differences could be understood by the reason that friction models used in MARS-MultiD were based on the experiment that had conducted in one dimensional pipe. For this reason, new friction models based on the multidimensional two-phase flow experiments should be developed for accurate calculation in MARS-MultiD.

4. Conclusion

In this study, the two-phase cross flow experiment was modeled by the MARS-MultiD. Compared with the experimental results, the calculated results by the code properly presented mass conservation which could be known from the relation between the liquid film velocity and thickness at the same flow rate. The magnitude and direction of the liquid film, however, did not follow well with experimental results. According to the results of Case-2, wall friction should be increased, and interfacial friction should be decreased in MARS-MultiD. These results show that it is needed to modify the friction models in the MARS-MultiD to simulate the two-phase cross flow.

Acknowledgement

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