Performance Tests for Bubble Blockage Device

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1. Introduction

Various safety systems have been designed and adapted in nuclear power plants to prevent postulated accidents, to enhance the life time and economic benefit, and increase public acceptance of the plants. Postulated severe core damage accidents have a high threat risk for the safety of human health and jeopardize the environment. Versatile measures have been suggested and applied to mitigate severe accidents in nuclear power plants. To improve the thermal margin for the severe accident measures in high-power reactors, engineered corium cooling systems involving boiling-induced two-phase natural circulation have been proposed for decay heat removal [1]. A boiling-induced natural circulation flow is generated in a coolant path between a hot vessel wall and cold coolant reservoir. In general, an increase in the natural circulation mass flow rate of the coolant leads to an increase in the critical heat flux (CHF) on the hot wall, thus enhancing the thermal margin [2].

In general, it is possible for some bubbles to be entrained in the natural circulation loop. If some bubbles entrain in the liquid phase flow passage, flow instability may occur, that is, the natural circulation mass flow rate may be oscillated. A new device to block the entraining bubbles is proposed and verified using air-water test loop.

2. Bubble blockage device and experimental method

Figure 1 shows a general natural circulation flow loop. As shown in Fig. 1, some pressure differences between the heating section and down-comer arise from the bubbles, which are generated on the heating surface, and a natural circulation flow should then be generated. If no bubble is entrained in the down-comer side, the natural circulation flow rate can be maximized. The proposed concept of a bubble blockage device is shown in Fig. 2. If there is no bubble blockage device, the liquid inlet velocity toward the down-comer, V_{dn}, may be large, and thus the bubble may be entrained to the down-comer. The proposed bubble blockage device plays a role in reducing the liquid inlet velocity, V_{in}, by enlarging the liquid inlet area toward the down-comer, A_{in}, compared with down-comer inlet area, A_{dn}. That is, as the area ratio, A_{in}/A_{dn}, increases, the velocity ratio, V_{in}/V_{dn}, decreases, and finally the momentum affected on the entraining bubbles shall decrease.

Figure 3 shows the air-water test facility to validate the bubble blockage device. As shown in Fig. 3, the two-phase flow is generated by injecting an air bubble. A 4-air injector is attached to the heating surface in Fig. 1 to generate the two-phase flow. An air injector with a diameter 70mm generates fine bubbles with a G2 glass filter. The void fraction in the heating channel can be estimated by the injected air flow rate and the circulated liquid flow rate as shown in Fig. 4. The water tank has a rectangular cross section, that is, 500×500mm^2. The gap size of the heating channel is 100mm, and the diameter of the down-comer pipe is 100mm.

To verify the performance of the bubble blockage device, the circulated liquid flow rate is constantly controlled by the pump system instead of the natural circulation flow generation. The circulated liquid flow rate is measured by a magnetic flow meter installed in the down-comer side. If the bubble is entrained in the down-comer, the magnetic flow meter signal may be degraded. That is, the degraded signal from the magnetic flow meter is used as an indicator of the entrained bubbles.

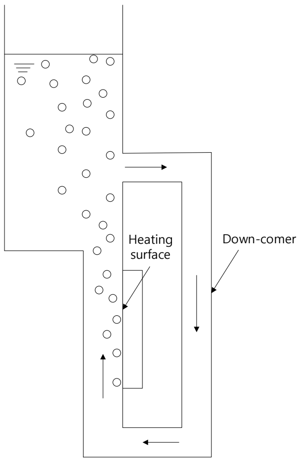

Fig. 1 Schematics of natural circulation flow loop

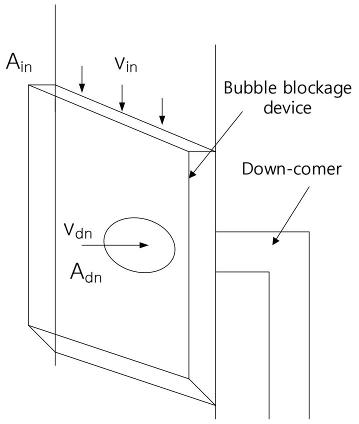

Fig. 2 Schematics of bubble blockage device

Fig. 3 Schematics of real-scaled natural circulation experimental facility

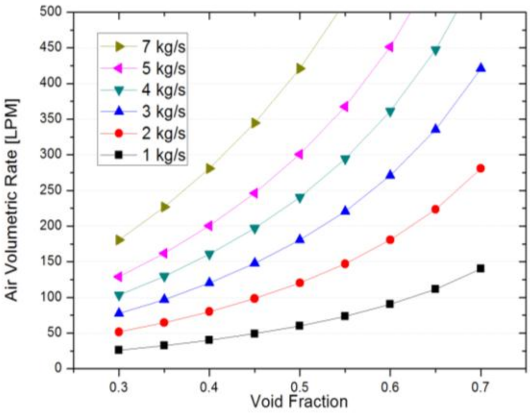

Fig. 4 Estimated void fraction with respect to the injected air flow rate and circulated liquid mass flow rate

3. Results and discussion

The tests for the bubble blockage devices are performed by varying the geometry and shape of the devices. The water level is 700mm from the down-comer inlet position. The tests are performed by increasing the circulated liquid mass flow stepwise under a constant air flow rate.

Figure 5 shows the measured circulation mass flow rate in the case of an area ratio, A_{in}/A_{dn}, of 1.9 with a device height of 300mm. As shown in Fig. 5, the bubbles are entrained if the circulation mass flow rate is larger than 4.7kg/s under a 280LPM the air injection rate.

Figure 6 shows the measured circulation mass flow rate in the case of an area ratio, A_{in}/A_{dn}, of 3.8 with a device height of 300mm. As shown in Fig. 5, the bubbles are entrained if the circulation mass flow rate is larger than 5.5kg/s under a 280LPM the air injection rate. Comparing Fig. 5 with Fig. 6, the bubble blockage effect is higher as the area ratio of the device increases.

Figure 7 shows the measured circulation mass flow rate in the case of an area ratio, A_{in}/A_{dn}, of 3.8 with a device height of 200mm. As shown in Fig. 7, the bubbles are entrained if the circulation mass flow rate is larger than 3.7kg/s under a 280LPM the air injection rate. Comparing Fig. 6 with Fig. 7, the bubble blockage effect is higher as the height of the device decreases.

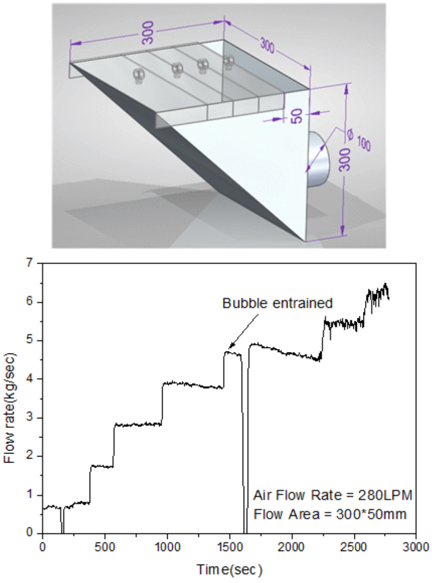

Fig. 5 Circulated liquid mass flow rate (A_{in}/A_{dn} : 1.9, height 300mm, without rim)

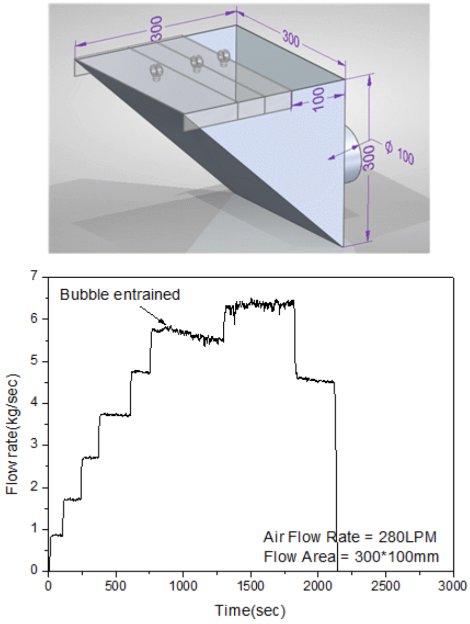

Fig. 6 Circulated liquid mass flow rate (A_{in}/A_{dn} : 3.8, height 300mm, without rim)

Figure 8 shows the measured circulation mass flow rate in the case of an area ratio, A_{in}/A_{dn}, of 3.8 with a device height of 200mm. As compared with that in Fig. 7, the device in Fig. 8 has a rim of 20mm on the top of the inlet. As shown in Fig. 8, the bubbles are entrained if the circulation mass flow rate is larger than 5.6kg/s under a 280LPM the air injection rate. Comparing Fig. 7 with Fig. 8, the bubble blockage is more effective if the devise has a rim under the same geometry conditions of the area ratio and height. This is why the vortex zone on the top of the inlet is generated by the rim of the bubble blockage device, as shown in Fig. 9.

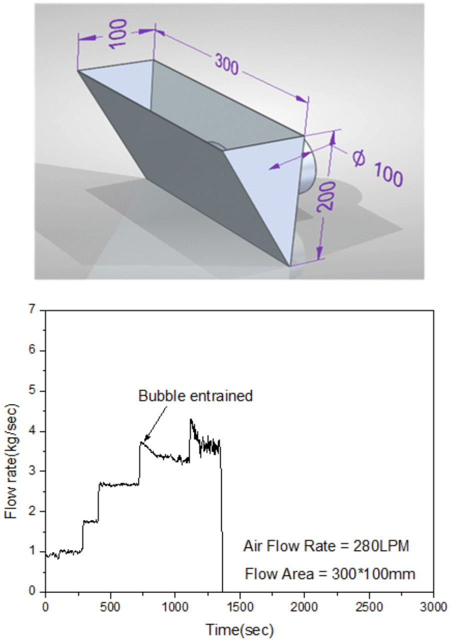

Fig. 7 Circulated liquid mass flow rate (A_{in}/A_{dn} : 3.8, height 200mm, without rim)

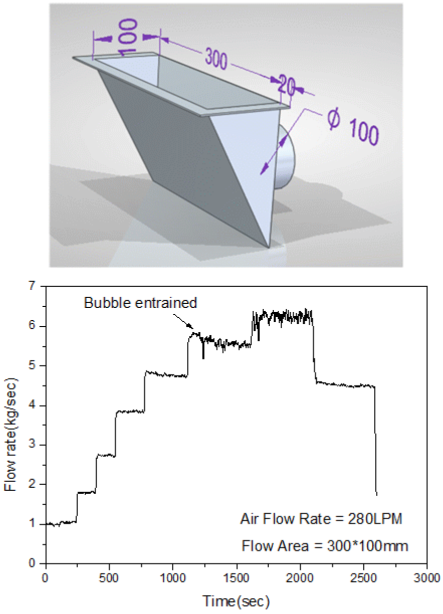

Fig. 8 Circulated liquid mass flow rate (A_{in}/A_{dn} : 3.8, height 200mm, with rim)

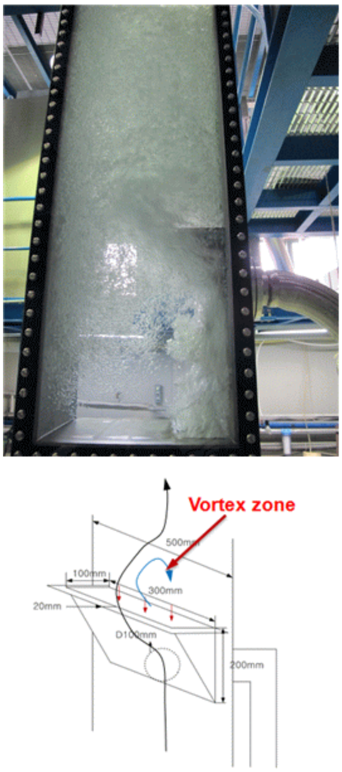

Fig. 9 Flow visualization results (A_{in}/A_{dn} : 3.8, height 200mm, with rim)

4. Conclusion

To avoid bubbles entrained in the natural circulation flow loop, a new device was proposed and verified using an air-water test loop. The air injection and liquid circulation loop was prepared, and the tests for the bubble blockage devices were performed by varying the geometry and shape of the devices. The performance of the bubble blockage device was more effective as the area ratio of the inlet to the down-comer increased, and the device height decreased. If the device has a rim to generate a vortex zone, the bubbles will be most effectively blocked.

ACKNOWLEDGMENTS

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