Measurement Techniques of Local Parameters in the Downcomer Boiling Experiment of APR1400

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1. Introduction

As one of the advanced design features of APR1400, the Direct Vessel Injection (DVI) mode as a safety injection system is adopted instead of a Cold Leg Injection (CLI) mode. Since several thermal-hydraulic phenomena are expected to happen in the downcomer, the experiment is required to observe and analyze the actual boiling phenomena. To do this, several parameters should be measured through the verification of their applicability [1]. In the present study, measurement techniques of the parameters are developed and their results are described herein [2]; local phase velocities and heat flux from the heated wall.

2. Measurement Techniques and Results

2.1 Measurement of Local Liquid Velocity

To measure the liquid velocity with unknown flow direction, a bi-directional pitot tube is developed. The developed pitot tube measures differential pressure at its both sides and it is converted to the velocity information using the developed calibration curve with 0.69 % deviation, which is obtained by several tests considering the temperature and hole size effects. By Bernoulli's equation with loss term and calibration test, the liquid velocity can be obtained by equation (1).

$$V_{liquid} = 0.395 \cdot \sqrt{\frac{2\Delta P}{\rho_{liquid}}} \qquad (1)$$

Twelve tests are performed according to varying distance from the heated wall, and the velocity profile at each location is obtained, as shown in Figure 4.

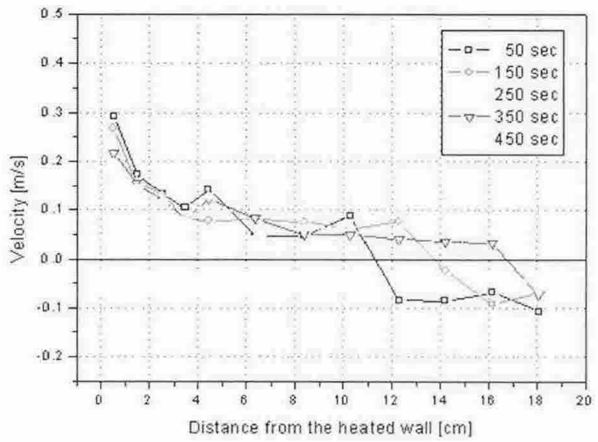

Figure 4 Liquid velocity profile along the distance from the heated wall

2.2 Measurement of Local Vapor Velocity

The high-speed camera (KODAK Motion coder SR-1000) is used to obtain the picture of vapor movement, which can take pictures up to 250 frames per a second.

During the tests, we can obtain two pictures with a certain time difference such as 1/125 sec, and measure the distance of vapor movement by merging these two pictures using the commercial software tool, Image-Pro. In the present study, one pixel in a picture is about 0.5 mm and it means that accuracy is affected by counting pixel error about 0.06 m/sec per pixel. Therefore, it is important to obtain clear and fine images

In the application of the proposed method to the downcomer boiling experiment, the local vapor velocity is properly measured, as shown in Figure 5. From the analysis between vapor size and velocity, it also turns out that the vapor velocity is rarely affected by the void size.

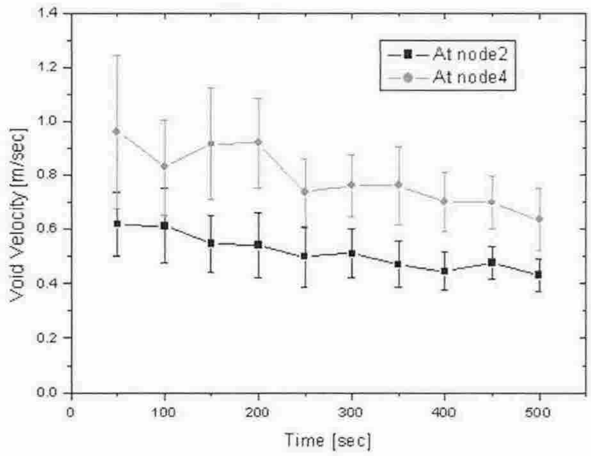

Figure 5 Local vapor velocity results

2.3 Measurement of Heat Flux from the Heated Wall

In the test facility [2], thermocouples are inserted with certain depth to measure the wall temperature distribution including the surface wall temperature. In order to measure the heat flux from the heated wall surface, the software-assisted heat flux measurement using two thermocouples and the 1-D conduction equation is developed based on solving 1-D conduction equation with initial and boundary conditions of temperature. Actually the thermocouple is located about 0.5~1 mm depth from the inner wall surface, so it is not the real inner surface temperature information strictly.

To measure heat flux more accurately, the predicted inner surface temperature is used as an inner boundary condition. According to Fourier's 1-D conduction law, predicted inner surface temperature is obtained by manual iteration using MARS code [3].

Figure 6 shows the heat flux measured at bottom of heated wall surface, which are insensitive parts to water level during downcomer boiling experiment.

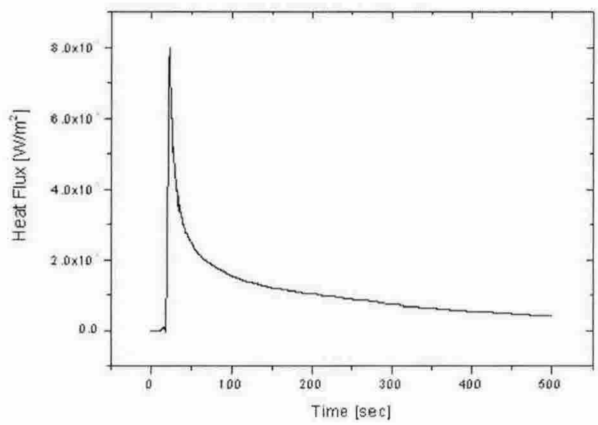

Figure 6 Heat flux result at the bottom of heated wall surface

3. Conclusion

An experimental study has been performed to develop the measurement techniques of local parameters such as local phase velocities and heat flux from the heated wall in the downcomer boiling experiment with DVI.

A bi-directional pitot tube is developed to measure the liquid velocity in both directions of 1-D flow through the modification of the existing pitot tube. In the actual experiment, the developed pitot tube and its calibration curve with 0.69% deviation are applied, and the local liquid velocity is measured successfully along the distance from the heated wall.

The high-speed camera and commercial software are used to measure the local vapor velocity and the procedure is confirmed in the present study. With 0.06 m/sec per pixel error, the local vapor velocity is properly measured. And it turns out that the vapor velocity is insensitive to void size.

In order to measure the heat flux from the heated wall in the downcomer boiling experiment, the software-assisted heat flux measurement technique is developed using two thermocouples and the conduction equation of MARS. The developed heat flux measurement method measures the heat flux very accurately even in the heat flux region with a sharp gradient in the downcomer boiling experiment.

REFERENCES

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