Air-water flow measurement for ERVC conditions by LIF/PIV

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1. Introduction

In-vessel retention through the external reactor vessel cooling (IVR-ERVC) is an important strategy during the severe accident. In the strategy, reactor cavity flooding system submerges the reactor vessel into the water and the decay heat of the molten corium in the reactor is cooled down. Critical heat flux (CHF) of the external reactor vessel wall is a safety limit that indicate the integrity of the reactor vessel during the situation. Many research conducted CHF experiments in the IVR-ERVC conditions [1, 2]. However, the flow velocity field which is an important factor in the CHF mechanism were not studied enough in the IVR-ERVC situations.

In this study, flow measurements including velocity vector field and the liquid velocity in the IVR-ERVC conditions were studied. An air-water flow measurement loop was set up and laser induced fluorescence/particle image velocimetry (LIF/PIV) technique was adopted to measure the velocity of the flow.

2. Experimental setup

2.1 Flow measurement loop configuration

The experimental flow loop is presented in Figure 1. It is composed of a test section, an air injection device, a surge tank, an upper plenum, a lower plenum, a pump and a flow meter. The reference apparatus was the CHF experimental water loop in KAIST [2].

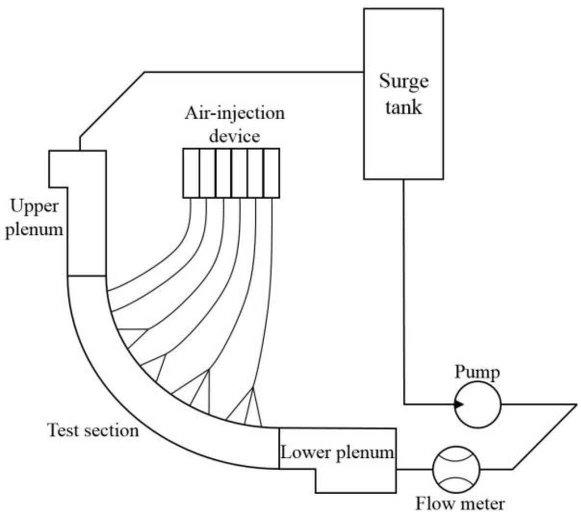

Fig. 1. Schematic diagram of flow measurement loop

To simulate a three-dimensional (3D) hemisphere shaped reactor lower head, the two-dimensional (2D) slice test section was designed. The test section was a rectangular flow channel which is bent for 90 degrees. The radius of the curvature was 0.5 m and it was corresponded 1/5 scale of APR1400 reactor design. The gap size was 0.06 m and width was 0.03 m. The test section was made of transparent acrylic.

2.2 Air injection mechanism

An air injection device was used to simulate the boiling phenomena in the experiment. Figure 2 shows the simulated heat flux distribution of the external reactor vessel during the severe accident. From the heat flux information, the vapor generation rate from the 2D slice test section was calculated. The amount of air equivalent to the vapor was injected into the test section.

The right side of the 2D slice which simulate the reactor vessel lower head had 12 equally-spaced holes. They are connected with the air injection device and the air injection flow rate was controlled steadily.

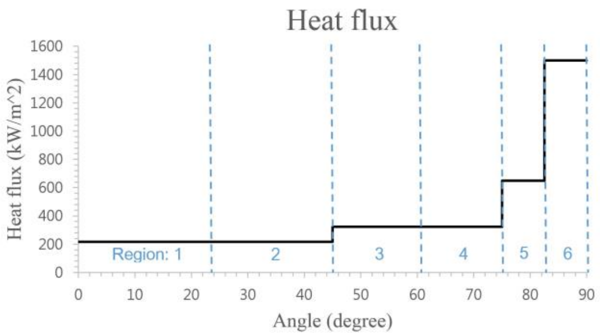

Fig. 2. Heat flux distribution of reactor vessel lower head

2.3 LIF/PIV system

An LIF/PIV facility was set up to measure the velocity field. 532 nm green laser with 4 W maximum power was used for light source. The high speed camera Fastcam Mini UX 50 from Photron, USA was used. The diameter of the fluorescent red particles was 53-63 μm. The particle emits 605 nm wavelength light when exposed to 530 nm wavelength laser. The particles were made of polyethylene microsphere. The density of the particle was 1.045 – 1.055 g/cc which is similar to water so it had a good tracking performance. For the LIF technique, an optical filter was adopted.

2.4 Experimental conditions

The working fluid was water under atmospheric pressure condition. The mass flux of the flow in this experiment were 100, 200, 300, 400, and 500 kg/㎡·sec. These flow conditions were selected to simulate natural circulation in IVR-ERVC situations [4]. The CHF data was adopted from Park et al [2]. The experiment were conducted with and without air injection conditions.

The pictures of the flow were taken at 90 degree of the curvature which simulate the top of the reactor vessel lower head. In PIV measurement, the resolution of the camera was 1280 × 1024 pixels. For the water flow experiment, the interrogation area size was 48 pixels. For the air-water two phase flow experiment, the interrogation area was 64 pixels. The step size was 50 % of the interrogation area. 3000 image pairs were averaged to analyze time-averaged result for each cases.

3. Results and analysis

3.1 Flow measurement without air injection

Firstly the flow measurement experiment without air injection case was conducted. Time-averaged velocity vector fields and contour magnitudes are displayed in Figure 3 from (a) to (e). The mean velocity of each flow cases were reasonable compared with mass flux input. The velocity profile was lean to the left side of the test section because the flow path was curved. Figure 4 shows the velocity profile of 400 kg/㎡·sec mass flux case. The average velocity was 0.4 m/sec. The maximum velocity was 0.47 m/sec.

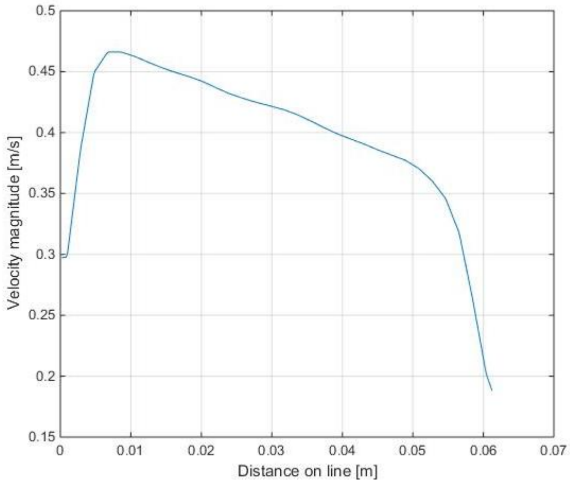

Fig. 4. Velocity profile of water flow, 400 kg/㎡·sec case.

3.2 Flow measurement with air injection

The quantity of the air equivalent to the vapor generation was injected. For 100 and 200 kg/㎡·sec mass flux case, a counter current flow was occurred. Air bubbles trapped at the upper part of the test section and swirled. PIV measurements in these region were very difficult because the bubble and fluorescence particles interference each other.

300 to 500 kg/㎡·sec mass flux cases were analyzed. (f), (g), and (h) in Figure 3 show the PIV measurement of air-water two phase experiment. For the 300 kg/㎡·sec mass flux case, the liquid velocity at the outside of two phase boundary layer was around zero to 0.1 m/sec. The maximum liquid velocity along the slug path way was 0.7 m/sec.

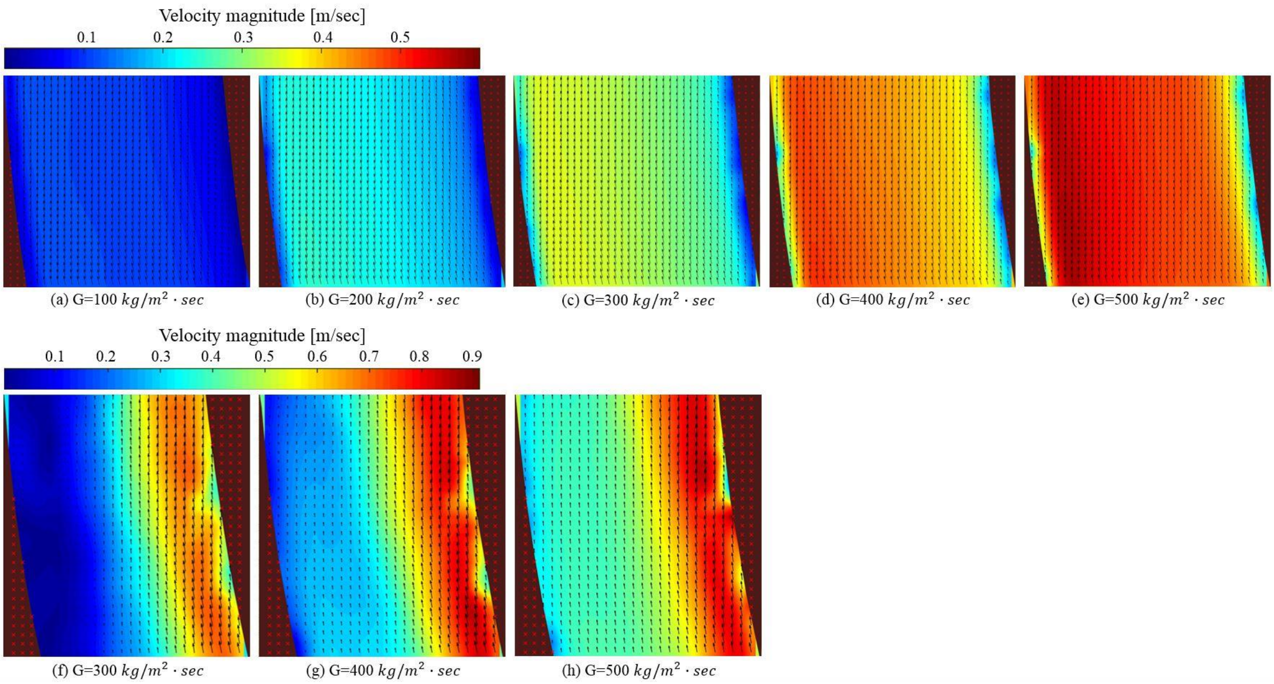

Fig. 3. Time-average velocity vector field

For 400 kg/㎡·sec case, the liquid velocity at the outside of two phase boundary layer was around 0.27 m/sec. The maximum liquid velocity along the slug path way was 0.8 m/sec. For 500 kg/㎡·sec case, the liquid velocity at the outside of two phase boundary layer was around 0.4 m/sec. The maximum liquid velocity along the slug path way was 0.8 m/sec.

Flow velocity near the right side of the test section which simulates heated reactor vessel wall was higher than the average velocity of the entire flow. Figure 5 shows the velocity profile of air-water experiment for 500 kg/㎡·sec case. As the inlet mass flux increase, liquid velocity at the outside of two phase boundary layer increased and two phase boundary layer thickness decreased.

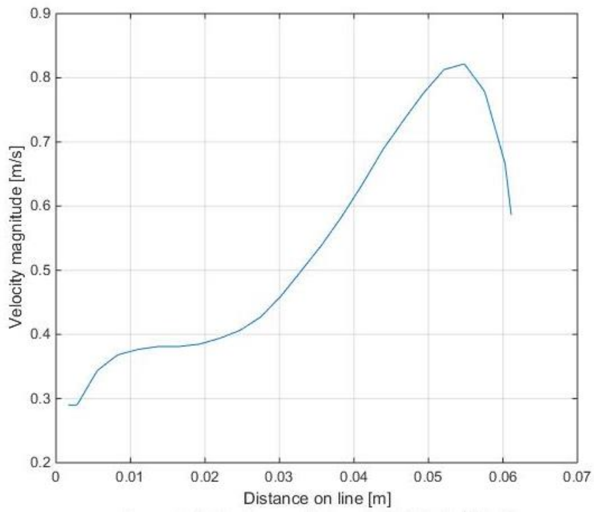

Fig. 5. Velocity profile of air-water flow, 500 kg/㎡·sec case.

4. Conclusions

The air-water two phase flow loop simulating IVR-ERVC conditions was set up and liquid velocity field was measured by LIF/PIV technique in this study. The experiment was conducted with and without air injection conditions. For the air-water flow experiment, liquid velocity at the outside of two phase boundary layer became higher and the two phase boundary layer thickness became smaller when the mass flux increases. The velocity data obtained in this study are expected to improve the CHF correlation in the IVR-ERVC situations.

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