Evaluation of Void Fraction Measurement Technique in TROI Experiments

S. H. Hong [a*], K. S. Ha[a], J. H. Kim [a], S. W. Hong[a]
[a]*Thermal Hydraulics Safety Research Division, KAERI, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: hsh4004@kaeri.re.kr*

1. Introduction

At the time of a core-melt accident (a severe accident) in a water-cooled nuclear power reactor, the molten core may interact with the coolant. Sometimes, this interaction is accompanied with destructive pressure waves due to an explosively rapid steam generation. This phenomenon is called a steam explosion. A steam explosion might breach the integrity of the reactor pressure vessel or containment to release harmful radioactive fission products to the public. Therefore, a steam explosion has been one of most the important severe accident issues since the TMI-2 accident.

KAERI (the Korea Atomic Energy Research Institute) started an experimental steam explosion program, the TROI (Test for Real cOrium Interaction with water) program[1-2]. In this program, spontaneous or triggered steam explosions have been observed with prototypic corium at a different ratio of UO_2 and ZrO_2 from that of the FARO/KROTOS experiments. According to the TROI program, it was found that component distribution in a pre-mixture at the time of an explosion, especially the void fraction, was affected by large uncertainties in the codes in the absence of detailed information on the pre-mixing zone internals, which differs from existing experimental data. Therefore, it is very important to measure the temporal void fraction on the pre-mixing zone in the TROI test. In this paper, the void evaluation by detection of differential pressure was checked and compared with alternative methods such as a level-swell meter and a high-speed visualization system for confirmation by scoping tests.

2. Experimental method and results

The TROI test facility was composed of a furnace, a furnace vessel, an interaction vessel, a pressure vessel, and an intermediate melt catcher. The furnace was a cold crucible to melt the corium by induction heating. The furnace vessel was a protection vessel surrounding the furnace. The interaction vessel was the test section in which a fuel coolant interaction occurred. The pressure vessel was a protection vessel surrounding the interaction vessel. Finally, the intermediate melt catcher played a role in controlling melt release conditions such as the melt diameter and release rate.

In the interaction vessel of the TROI facility, three differential pressure transmitters were mounted on the interaction vessel to measure the average void fractions between 0.2 m to 0.4 m, 0.4 m to 0.6 m, and 0.6 m to 0.8 m from the bottom of the interaction vessel (Rosemount 3051S, VFDP101 ~ VFDP103), as shown in Fig. 1.

A scoping test facility was prepared to check the void evaluation by detection of the differential pressure, as shown in Fig. 2. The scoping test facility is a wide cylindrical acryl vessel of 0.6 m in diameter and 1.5 m in height with a thickness of 10 mm at the sidewall to simulate the interaction vessel of the TROI facility. An air injection hole was installed on the bottom of the test facility to generate some void fraction distribution in the scoping test vessel.

The void fraction in the scoping test vessel was measured by both three differential pressure transmitters and a level swell meter simultaneously. Three differential pressure transmitters were mounted on the scoping test vessel to measure the volume-averaged void fractions between 0.2 m to 0.4 m, 0.4 m to 0.6 m, and 0.6 m to 0.8 m from the bottom of the vessel. The level swell meter was installed in the center of the vessel. The meter is a TDR-type (time domain reflectometry) probe which allows a fast response time (~1 kHz) and is able to detect gas/water surface intersecting it even in the case of high-gas content in water (high void fractions). The same type of probe has been used to measure a water level swell during the pre-mixing phase for the estimation of the integral vapour fraction in the mixing zone in the KROTOS test.

For the scoping test, water was filled up to a 1 meter level in the test vessel, and then the air was supplied during a short time by operating the air valve. The data from the differential pressure transmitters and level swell meter were acquired with a sampling rate of 1,000Hz by the NI USB-6212 data acquisition board (National Instruments Co.). A high-speed digital video camera (Phantom Miro 3.0, 512×512 pixels at 800 fps) was also used to visualize the bubble behaviors and water level.

Fig. 3 and Table 1 show the scoping test results by differential pressure transmitters and the level swell meter. The void fractions measured by differential pressure transmitters sequentially increased from the bottom to the top region of test vessel because the bubbles gradually rose to the surface. Fig. 4 shows a visualized photograph on the water surface at the highest level by the high-speed camera. As shown in Fig. 4, the maximum water level reached 1,054mm. If it is assumed that the distribution of a radial void fraction is similar to a parabolic function and the radial shape of the void fraction does not vary along with height, the volume-averaged void fraction is 50% of the central (maximum) void fraction as shown in Eq.(1). By the scoping test, the central void fraction was calculated as 0.054 based on the water level swell measurement by the high-speed video camera. The volume-averaged void fraction measured by the VFDP103 at the upper volume was 58% of the central (maximum) void fraction measured by the high-speed camera. Therefore, the void fraction by differential pressure is plausible in TROI tests.

$$\bar{\alpha} = \frac{1}{V}\int_V \alpha(r,z)\,dV = \frac{1}{\pi R^2 \Delta H}\int_{H1}^{H2}\int_0^R \alpha(r,z)2\pi r\,drdz \\ = \frac{1}{\pi R^2 \Delta H}\int_{H1}^{H2}\int_0^R \alpha_{\max}\left(1-\frac{r^2}{R^2}\right)2\pi r\,drdz = \frac{\alpha_{\max}}{2} \quad (1)$$

3. Conclusion

In this paper, the void evaluation by detection of differential pressure was checked and compared with alternative methods such as a level-swell meter and a high-speed visualization system for confirmation by scoping tests. From the scoping test using differential pressure transmitters, a water level swell meter, and a high-speed video camera, the void-fraction measurement technique by a differential pressure of the TROI test is plausible temporally and quantitatively.

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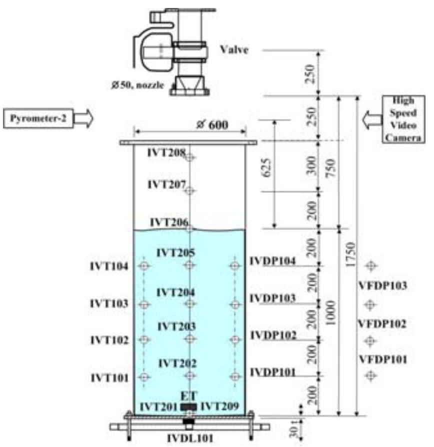

Fig. 1. Schematic diagram of the interaction vessel in the TROI facility (unit : mm).

Table 1. Scoping test results

Time (sec)	Maximum signal (instrument)
2.0185	VF 0.0436 (VFDP101)
2.3040	VF 0.0445 (VFDP102)
2.6555	VF 0.0313 (VFDP103)
2.8040	Level 1,040mm (level swell meter)

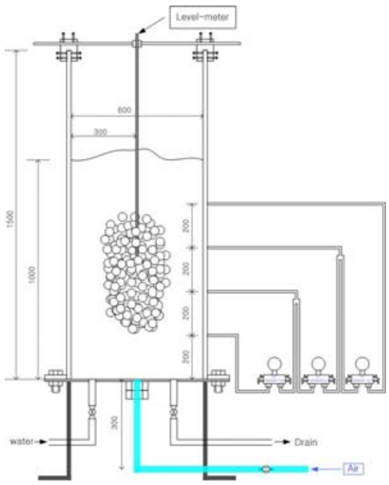

Fig. 2. Schematic diagram of the scoping test facility (unit : mm).

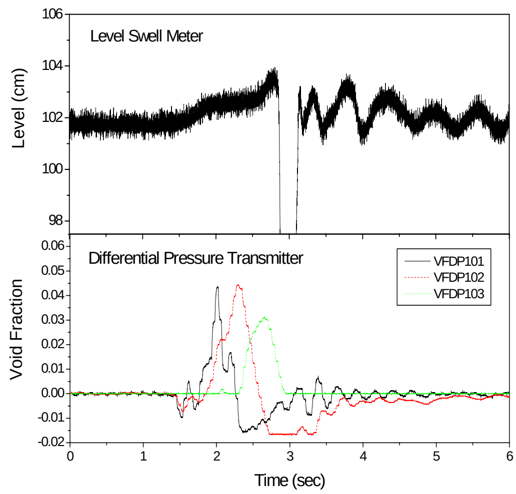

Fig. 3. Scoping test results (level swell meter and DP)

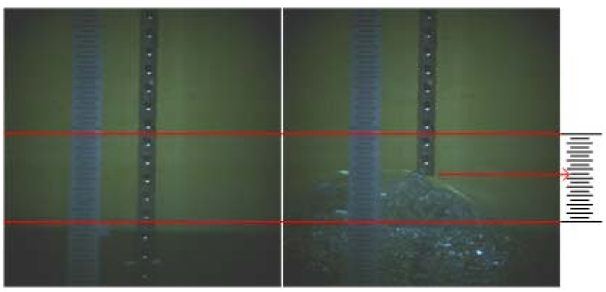

Fig.4. Scoping test results
(visualization by high speed camera)