Fuel-Coolant Interaction visualization in TROI test facility

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1. Introduction

Under a severe accident, the reactor cavity integrity can be threatened with a molten Fuel-Coolant Interaction (FCI). Thermal energy transfer from a high temperature molten core material to coolant water within a short time causes force to damage the surrounding structures. Previous experimental studies simulated the molten corium injecting from the reactor vessel failure to the cavity partially filled with water [1]. However, In-Vessel Retention (IVR) concepts floods the reactor cavity under a severe accident, which causes the corium melt release into water without a free fall between the reactor vessel failure and a pool of water in the reactor cavity. It is necessary to observe the FCI phenomena at the condition of vessel failure to IVR. We carried out a visualization test on the interaction of a corium melt and water to observe the premixing phase without a free fall of a melt jet in a gas phase before contacting the cooling water. This paper is based on the previous study presented at Ninth Korea-Japan Symposium on Nuclear Hydraulics and Safety [2], we added the results on sieved debris distribution.

2. TROI test facility

A previous TROI (Test for Real cOrium Interaction with water) test facility was modified to make the desired FCI condition in which the corium melt was released directly into water without a free fall in a gas phase. Before the corium melt reacts with a coolant, it stays in a short time at the releasing valve located just above the water level, as shown in Fig. 1. The TROI test facility consists of the two vessels described below:

(1) The upper vessel includes a cold crucible to make the superheated corium melt.

(2) The lower vessel includes an interaction vessel filled with sub-cooled water to observe the FCI.

3. Experimental procedure

This visualization test proceeded sequentially as described below:

(1) Making the corium melt: The mixture of the uranium oxide pellet and zirconium oxide powder with the weight ratio of 80 to 20 respectively, was charged in a cold crucible to make the corium of 34 kg. The corium melt was generated by the induction heating method.

(2) Delivering the corium melt: A cold crucible was blocked by a cylindrical plug, and a thin crust layer on the bottom of a crucible was created in the melting process. The plug was removed, and a puncher broke a thin crust layer on the bottom of the crucible. The corium melt dropped on the closed releasing valve.

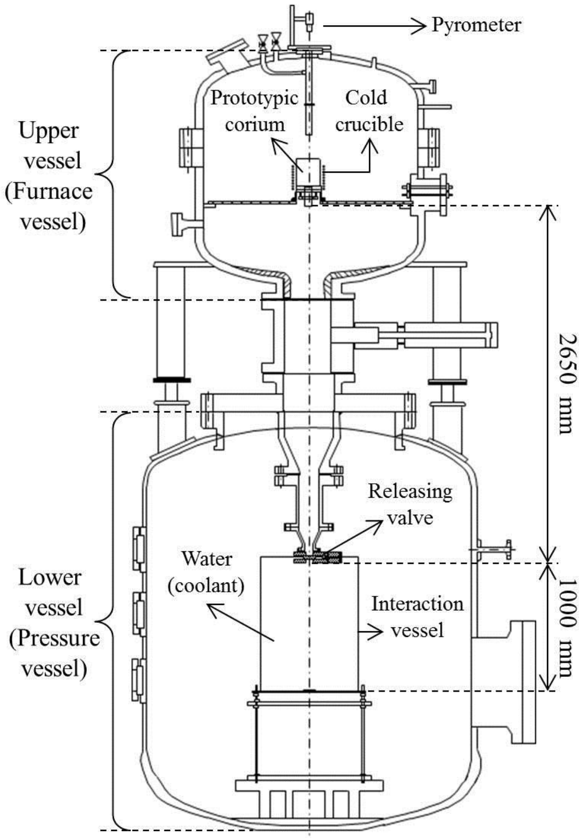

Fig. 1. TROI test facility for FCI to simulate IVR [2].

(3) Reacting corium melt with a coolant: The corium melt was released into the water level and penetrated through a coolant in an interaction vessel as soon as the releasing valve opened.

A square interaction vessel with 600 mm in length and 1200 mm in height has three transparent side surfaces for the visualization test. A high-speed camera (Phantom, V4.2) recorded the behavior of the corium melt penetrating through water in time. In addition, the temperature variations in time and in a direction of a falling melt jet were measured by twenty-six thermocouples. To observe the premixing in the FCI, the temperature measured by the sacrificial thermocouples can be compared with the visualization taken by the high-speed camera.

4. Results

Figure 2 shows a high-speed camera image of the corium melt penetrating into water from 0.3 seconds to 0.6 seconds, where the time is zero when the releasing valve is open. The video recorded in a real time was compared with the measured temperature by the sacrificial thermocouples within water, as shown in Fig. 3, where the measured time in the thermocouple was synchronized with that in the visualization test. It was observed clearly that the sacrificial thermocouples installed from 800 mm to the bottom of the interaction vessel were cut sequentially by a falling corium melt jet.

Fig. 2 High-speed camera image of a corium melt jet [2].

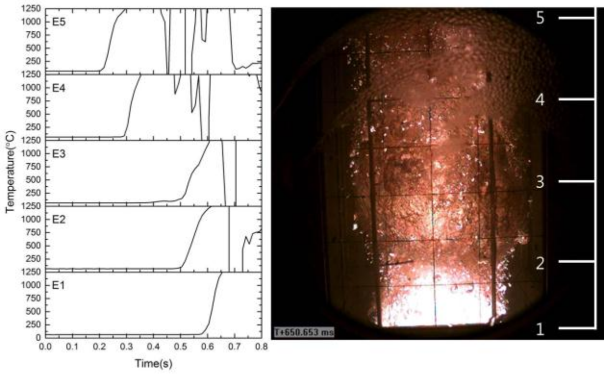

Fig. 3 Temperature measured by thermocouples and visualization taken by high-speed camera [2].

After the test, the debris accumulated at the bottom of the interaction vessel was collected and then they were dried in an oven. The debris was sieved and weighed, as shown in Fig. 4. The cumulative mass fraction of the debris smaller than 1.0 mm was 15%. The mass mean diameter of the collected debris was 2.9 mm.

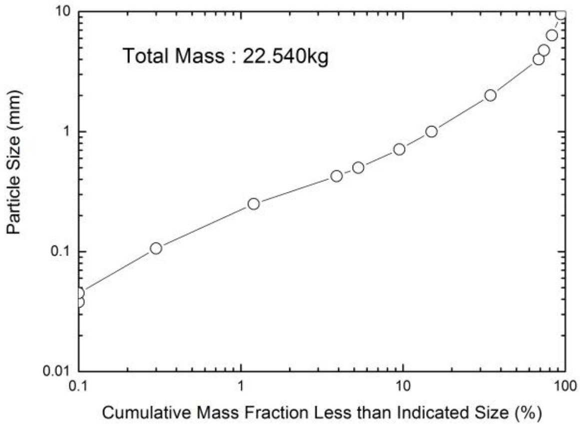

Fig. 4. Sieved debris distribution.

5. Conclusions

The visualization test on the FCI without a free fall of a corium melt jet in a gas phase was conducted carefully in the TROI test facility. A prototypic corium consisting of uranium oxide and zirconium oxide with a weight ratio of UO_2 to ZrO_2 of 80 to 20, respectively, was heated up using the induction heating method. It was observed that a corium melt jet penetrated into water with 1000 mm in depth, and it took about 0.6 seconds from opening the releasing valve, which was confirmed by the sequential variation of the temperature measured by the sacrificial thermocouples installed in the direction of a falling melt jet. The cumulative mass fraction of the debris smaller than 1.0 mm was 15%, and the mass mean diameter of the debris was 2.9 mm.

This visualization test can generate the valuable information such as the behavior of the corium melt jet and the size of mixing zone for validating the computer code. Further studies on the FCI with an external triggering are necessary to assess the integrity of a reactor cavity under the IVR condition.

Acknowledgements

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References

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