An Experimental Observation of Fuel Coolant Interaction using ZrO_2 Under Conditions of a Reactor Submerged by Water

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1. Introduction

Most tests on fuel coolant have been performed under conditions with some distance from a furnace chamber to retain the molten material before melt release into an interaction chamber with water. In other words, a molten material is injected into an interaction chamber with free fall [1, 2]. This type of fuel coolant interaction can occur in operating plants. However, the flooding of a reactor cavity is considered as SAM measures for new PWRs such as APR-1400 and AP1000 to assure the IVR of a core melt. In this case, a molten corium in a reactor is directly released into the water surrounding the reactor vessel without free fall. Only few experimental data to this kind of fuel coolant are available [3] and the data using corium is not available. Therefore, KAERI have carried out tests to simulate fuel coolant interaction using ZrO_2 under reactor conditions submerged by water. This paper presents the first observation from the tests.

2. Test Results

2.1. Experimental Facility

The TROI experimental facility is composed of a furnace vessel (upper vessel), a pressure vessel (lower vessel), an intermediate valve and an interaction vessel, as shown in Figure 1.

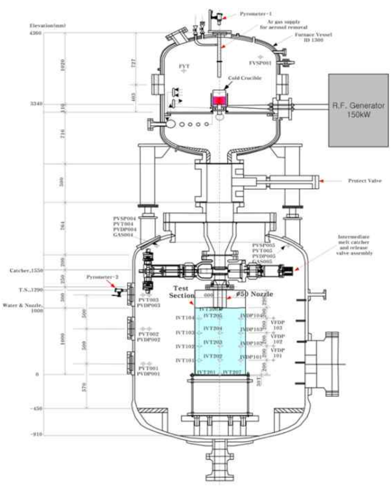

Fig. 1 Schematic of TROI

After the melt is generated and superheated sufficiently in the cold crucible, at a required melt temperature, a plug is removed and a puncher is actuated pneumatically. Melt is discharged by gravity and is accumulated in the intermediate valve for around 1 second. Melt is delivered into the water in the interaction vessel by opening the slide located below the intermediate valve. More details of the TROI facility including the data measurement is described in reference [4].

2.2 Results

Table 1. Initial conditions and results

TROI test number	Unit	TROI76-W4	TROI77-W5
Melt			
Initial Charge			
Composition / ZrO2 /Zr	[w/o]	99.5/0.5	0/99.5/0.5
Temperature	[K]	3040	3000
Charged mass	[kg]	17.890	16.795
Initiator mass	[kg]	0.089	0.90
Released mass	[kg]	11.916	9.689
Plug/puncher diameter	[cm]	10.0/8.5	10.0/8.5
Initial jet diameter	[cm]	5.0(nozzle)	5.0(nozzle)
Free fall in gas	[m]	-0.01	-0.01
Test Section			
Water mass	[kg]	360	283
Initial height	[cm]	100	100
Final height	[cm]	92.8	24.8
Cross section	[m2]	0.36	0.283
Initial temperature	[K]	341	341
Sub-cooling	[K]	32	32
Pressure Vessel			
Initial pressure(air)	[MPa]	0.140	0.116
Initial temperature	[K]	311	298
Free volume	[m3]		
Results			
Max. PV pressurization	[MPa]	0.020	0.061
Time to reach peak	[sec]	4	2.3
Maximum PV heat-up	[K]	31	54
Time to stabilize	[sec]	14	
Max. water heat-up	[K]	34	19
Time to stabilize	[sec]	10	16
Max. void fraction	[%]	~6	~3
Steam explosion		No	Yes
Dynamic pressure peak	[MPa]	0	13.4
Duration	msec		
Impulse	kN		438
Duration	msec		
Debris			
Total	[kg]	11.916(100%)	9.689(100%)
>6.35mm	[kg]	4.905(41.2%)	0.060(0.6%)
4.75mm ~ 6.35mm	[kg]	2.715(22.8%)	1.157(11.9%)
2.0mm ~ 4.75mm	[kg]	3.451(29.0%)	1.867(19.3%)
1.0mm ~ 2.0mm	[kg]	0.650(5.5%)	1.285(13.3%)
0.71mm ~ 1.0mm	[kg]	0.095(0.8%)	0.535(5.5%)
0.425mm ~ 0.71mm	[kg]	0.060(0.5%)	0.825(8.5%)
<0.425mm	[kg]	0.040(0.3%)	3.960(40.9%)

A TROI76-W4 test was carried out without a triggering to induce a steam explosion. The square rectangular interaction chamber, a 1m water pool with an inner cross section of 60cm x 60cm, is used to visualize the mixing zone, the melt front velocity in the water and the water level swell. The water level swell will be used to verify the void fraction measured by differential pressure sensors. In the TROI77-W5 test, a cylindrical hard tank, a 1m water pool with 60cm in a diameter, is used to prevent the destruction of the tank by a steam explosion. The visualization inside of the interaction chamber is not possible. A triggering was applied during the test.

Fig. 2 shows the picture just before the melt reached the bottom of the interaction chamber of TROI76-W4. The mixing zone size is about 20 cm. This mixing zone size will be used for code validation.

Fig. 2 Mixing zone for TROI76-W4

Fig. 3 shows the dynamic pressure measured at the inner surface of the interaction chamber in the TROI76-W4 test. The dynamic pressure was not detected because there was no steam explosion. Therefore, the force measured at the bottom of the interaction during an explosion was not detected.

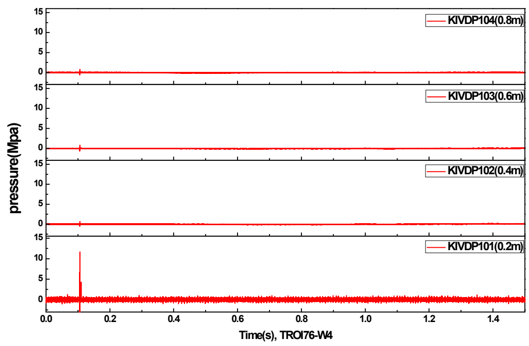

Fig. 3 Dynamic pressure for TROI76-W4

Fig. 4 shows the dynamic pressure of the TROI77-W5 test. The maximum dynamic pressure is about 10 MPa. Fig.5 shows the force measured at the bottom of the interaction during the explosion. The black dotted line of the figure is the force measured by the triggering without melt injection. The red solid line is the force by explosion with triggering. The first peak is caused by the triggering and the signal from the second peak is caused by a steam explosion. The peak force is about 400 kN. The span of the force is about 8ms.

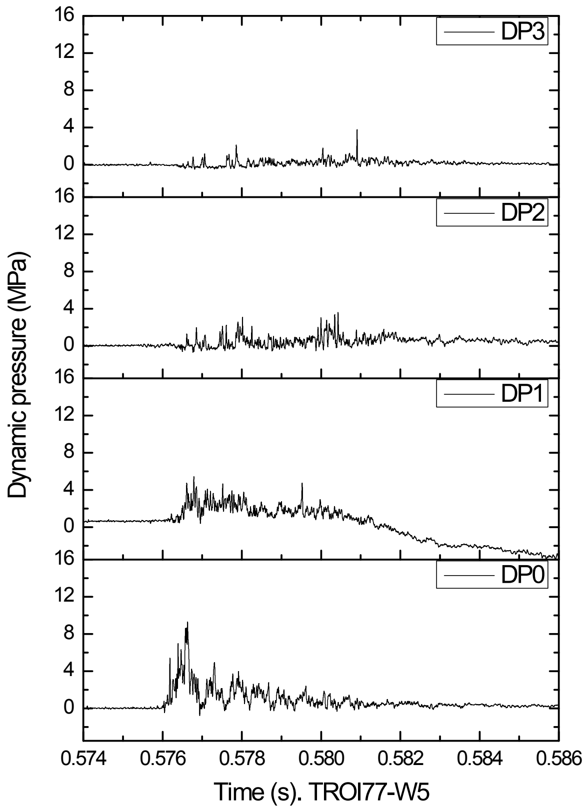

Fig. 4 Dynamic pressure for TROI77-W5

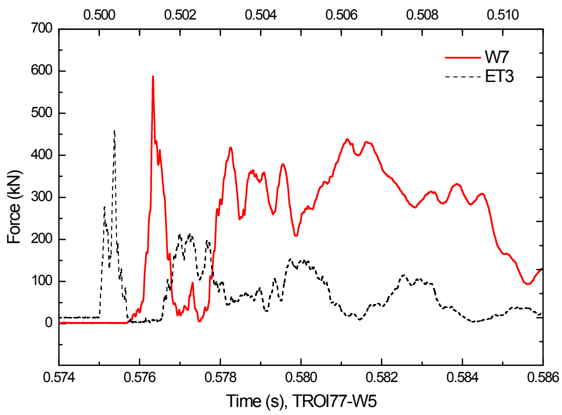

Fig. 5 Force for TROI77-W5

The maximum void fraction just before the melt reaches the bottom of the interaction chamber at around 0.55 sec in the TROI76-W4 is higher than at around 0.5 sec in the TROI76-W4, as shown in Fig. 6 and Fig. 7. However, the average void fraction of the three spans in both tests seems to be similar.

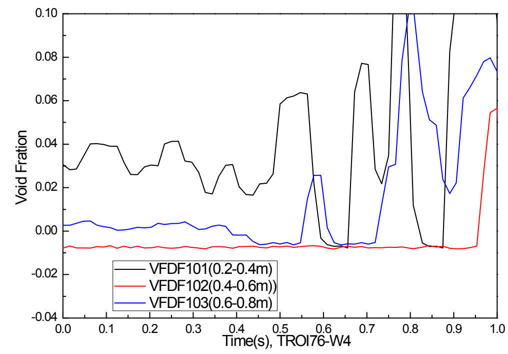

Fig. 6 Void fraction for TROI76-W4

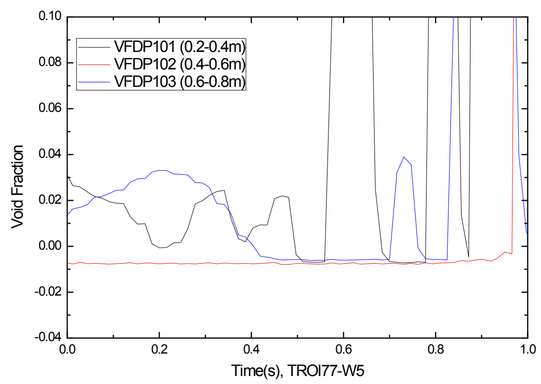

Fig. 7 Void faction for TROI77-W5

After the test, the debris size was sieved. As shown in Table 1, in the TROI76-W4 where there was no steam explosion, the fraction of debris less than 1mm is about 1.6%. However, In the TROI77-W5, the fraction of debris of less than 1mm takes 55%. This is the proof there was an explosion in the TROI77-W5.

3. Conclusions

KAERI have carried out tests to simulate a fuel coolant interaction using ZrO2 under the reactor conditions submerged by water. A steam explosion has been always observed when ZrO2 melt is released into interaction chamber with a free fall. However, under the reactor conditions submerged by water, a steam explosion was not observed when a triggering was not applied. The reason will be clarified by comparing with the experimental data with a free fall in the future. The experimental data production using the prototypic reactor materials of the mixture of UO2/ZrO2 is planned.

ACKNOWLEGEMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2012M2A8A4025889).

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