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Mixing Characteristics during Fuel Coolant Interaction under Reactor Submerged Conditions

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1. Introduction

Most tests on fuel coolant have been conducted under conditions with certain distance from a furnace chamber where a molten material before melt release is retained in an interaction chamber. In other words, a molten material is injected into an interaction chamber by free gravitation fall [1]. This type of fuel coolant interaction could happen to 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 injected into water surrounding the reactor vessel without a free fall. KAERI has carried out fuel coolant interaction tests without a free fall using ZrO_2 and corium to simulate the reactor submerged conditions.

There are four phases in a steam explosion. The first phase is a premixing phase. The premixing is described in the literature as follows: during penetration of melt into water, hydrodynamic instabilities, generated by the velocities and density differences as well as vapor production, induce fragmentation of the melt into particles; the particles fragment in turn into smaller particles until they reach a critical size such that the cohesive forces (surface tension) balance exactly the disruptive forces (inertial); and the molten core material temperature (>2500 K) is such that the mixing always occurs in the film boiling regime of the water: It is very important to qualify and quantify this phase because it gives the initial conditions for a steam explosion

This paper mainly focuses on the observation of the premixing phase between a case with 1 m free fall and a case without a free fall to simulate submerged reactor condition.

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 Fig. 1.

After the melt is generated and superheated sufficiently in the cold crucible, at the 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 s. The 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 [2].

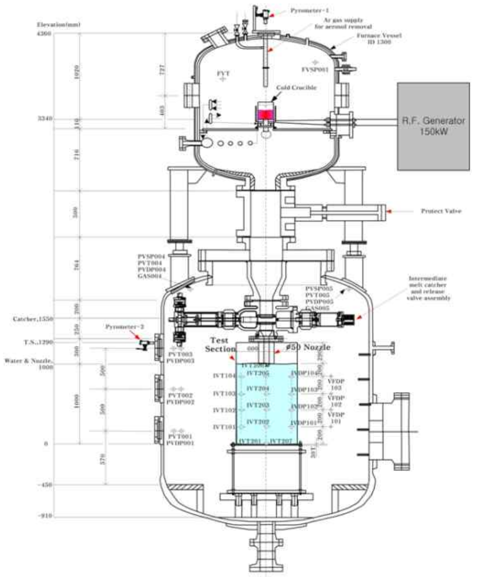

Fig. 1 Schematic of TROI

2.2 Results

Test results using ZrO2 under rector conditions submerged without a free fall were presented at last spring's KNS meeting in 2014 [3]. The initial conditions and major results were described therein. Here, the melt front velocity and bubble characteristic are investigated to obtain insight on the premixing behavior.

Fig. 2 Melt front images contacting the water surface and the bottom of the interaction chamber

Fig. 2 is shows an image taken using a high-speed camera at the window of the same level with the water surface. The melt is injected at 185ms and reached the bottom of the interaction chamber at 630ms. Therefore, the average velocity melt front passing a 1 m water pool is about 2.3m/s. The large bubble was generated at the melt jet surface and then went up, as shown in the right-side image in Fig. 2.

An FCI test using corium under reactor submerged conditions was also carried out. The test conditions are the same with the ZrO2 test except for the composition. The TROI79-W7(Sub) of Table 1 shows the initial conditions for the submerged case without a free fall.. For a comparison of the mixing characteristics with a 1 m free fall case, the initial conditions of TROI68-VISU(Free) are described in Table 1.

Table 1 Initial conditions

TROI test number	Unit	TROI79-W7(Sub)	TROI68-VISU(Free)
Melt			
UO2/ZrO2	[w/o]	80:20	80:20
Temperature(Max.)	[K]	~3,000K	~3,000K
Charged mass	[kg]	17.890	16.795
Released mass	[kg]	11.916	9.689
Plug/puncher diameter	[cm]	10.0/8.5	10.0/8.5
Jet diameter	[cm]	5.0(nozzle)	5.0(nozzle)
Nozzle to water surface	[m]	-0.01	-0.01
Test Section			
Water mass	[kg]	360	283
Initial height	[cm]	101	101
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

The melt is injected at 235 ms and reaches the bottom of the interaction chamber at 620ms, as shown in Fig. 3. The average velocity melt front passing the 1m water pool is about 2.7 m/s. It was found that the average velocity of corium, 2.7 m/s, is a litter faster than that of ZrO2, 2.3m/s, in water. A large bubble was also generated at the melt jet surface and then went up, as shown in the right-side image in Fig. 3. This characteristic is almost the same as the ZrO2 case, as shown in the right-side image in Fig. 2.

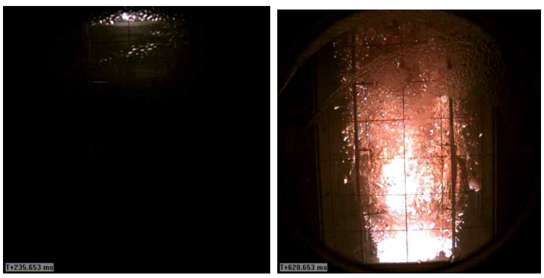

Fig. 3 Melt front images contacting the water surface and the bottom of interaction chamber (TROI79-W7(Sub))

The average velocity of the melt front is estimated using the signals from sacrificial thermo couples located in the center of interaction chamber. Fig. 4 shows signals from the sacrificial thermo couples. The average velocity passing through 800 mm to the bottom from the interaction chamber is about 2.3m/s. It is almost the same as the value estimated by video, 2.7m/s.

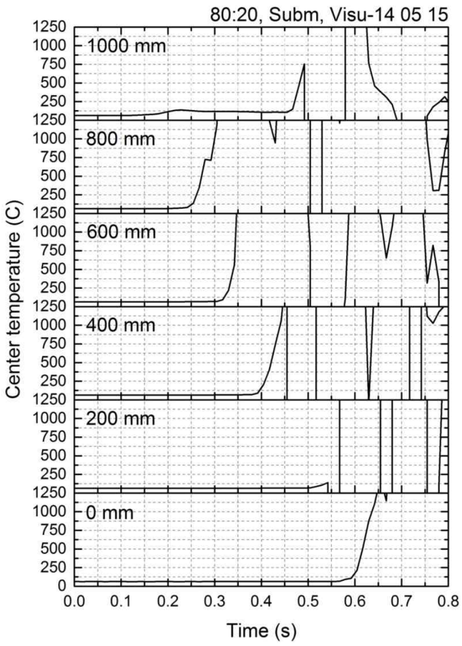

Fig. 4 Signals of Sacrificial Thermo couples (TROI79-W7(Sub))

Meanwhile, TROI68-VISU with a 1 m free fall is also observed. The melt is injected at 460 ms and reaches the bottom of the interaction chamber at 1060 ms, as shown in Fig. 5. The melt front velocity passing through a 1m water pool is about 1.7 m/s. From the signal from sacrificial thermo couples, the average velocity passing through 800mm to 400mm from the interaction chamber, as shown in Fig. 6, is about 1.8m/s. It is almost the same as the value of 1.7 m/s, as estimated by video.

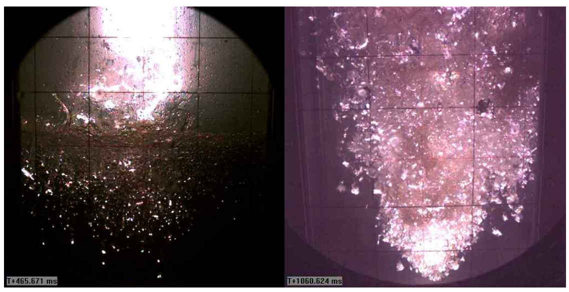

Fig. 5 Melt front images contacting the water surface and the bottom of interaction chamber (TROI68-VISU(Free))

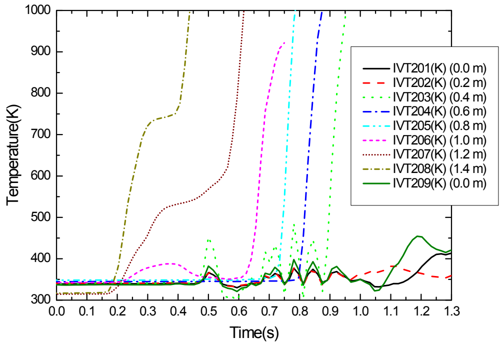

Fig. 6 Signal of sacrificial thermo couples (TROI68-VISU(Free))

In TROI68-VISU with a 1 m free fall, a number of small bubbles surrounding the particles were generated, as shown in the right-side image in Fig. 5. This observation is totally different with TROI79-W7(Sub) to simulate the reactor condition submerged without a free fall. The size of mixing zone is normally defined as the region existing as melt drops, steam void, and water, simultaneously. As shown in the right-side images in Fig. 3 and 5, the size of mixing zone without a free fall is relatively smaller than the 1 m free fall case.

3. Conclusions

The premixing behavior between a 1m free fall case and reactor case submerged without a free fall is observed experimentally.

<u>The average velocity of the melt front passing through 1m water pool;</u>

- Case without a free fall: The average velocity of corium, 2.7m/s, is faster than ZrO2, 2.3 m/s, in water.

- Cases of with a 1 m free fall and without a free fall : The case without a free fall is about two times faster than a case with a 1 m free fall.

<u>Bubble characteristics;</u>

- Case without a free fall: a large bubble surrounding the melt jet column is generated and went up.

- Case with a 1 m free fall: Lots of small bubbles surrounding the particles were generated. They stays in the mixing zone for the a relatively longer time.

<u>Mixing Zone;</u>

- The size of the mixing zone without a free fall shows a relatively smaller size mixing zone compared to a case with a 1 m free fall.

The reason for the difference between the two cases will be continuously analyzed. This observation will contribute to the development of an idea for the premixing modeling and the validation of the FCI cods.

ACKNOWLEGEMENTS

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