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Temperature Measurement of Molten Melt with High Melting Point in a Cold Crucible

S.W. Hong, J. H. Kim, K. S. Ha, B.T. Min, J. H. Park, S. H. Hong,

Korea Atomic Energy Research Institute
swhong@kaeri.re.kr

1. Introduction

Korea Atomic Energy Research Institute (KAERI) has conducted the TROI (Test for Real cOrium Interaction with water) program for a study on a fuel-coolant interaction (FCI). OECD/NEA launched SERENA project [1] to resolve the uncertainties with advanced instrumentations to clarify the nature of a prototypic material with mild steam explosion characteristics. The project has been operated by CEA using the KROTOS experiments and by KAERI using the TROI experiments, as the Operating Agents. This paper focused on the melt temperature measurement to reduce the uncertainty in modeling.

2. Melt Temperature measurement and analysis

2.1 importance of melt temperature

Reactor conditions for FCI analysis are not always best resembled in small scale experiments. The same melt superheat in reactor and experimental conditions will probably result in different FCI behavior, influencing the melt solidification dynamics due to different melt (and premixture) volume to surface ratios. Lots of experimental results generally show that the higher superheat causes the higher load. However, there is a critical value to the melt superheat to increase the load. For the extrapolation of experimental findings to reactor conditions, it is necessary for the melt superheat in the experimental condition to maintain highly as possible because the computer code is validated for reliable extrapolation.

2.2 Melt temperature measurement in TROI

2.2.1. Test conditions

Fig. 1 shows melt temperature measurement concept in TROI test facilities. Two optical pyrometers are employed to measure the melt temperatures in the furnace and at the melt delivery path just below the quick-opening valve, respectively. To measure the melt temperature in the crucible during melting through a quartz window, from the top of the furnace vessel, the argon gas supply system is used to prevent optical noises generated from participating media (aerosols) in the optical path(See the left of Fig. 2). The other optical two-color pyrometer is directed to the melt delivery path to measure the melt temperature at the time of melt delivery through a quartz window directly below the quick-opening valve (See the right of Fig. 2).

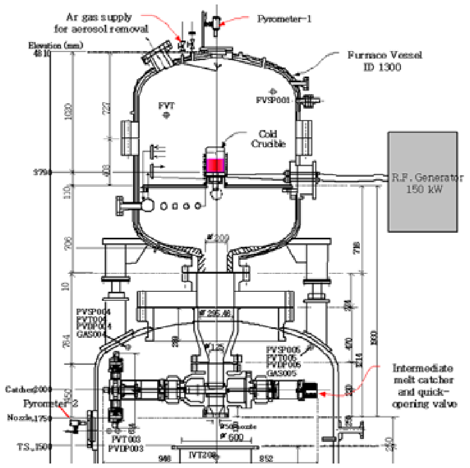

Fig. 1 Melt Temperature Measurement Location

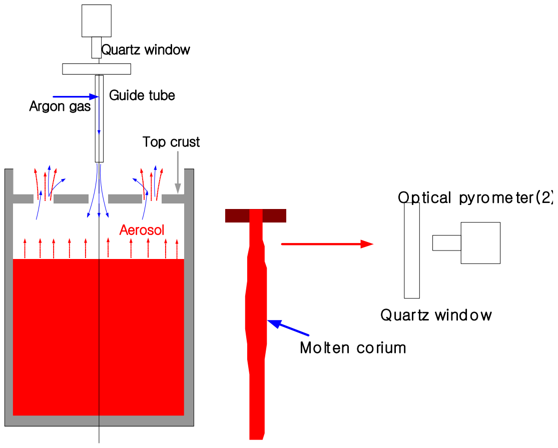

Fig. 2 Detail Concept for Temperature Measurement

2.2.2 Melt temperature

Fig. 3 shows the melt temperature during the melting process at the top of the furnace vessel for the Case 1 without cooling and reheating. The melt temperature starts increasing at 875 sec and reached to a maximum value of 2,920 K at 2,050 sec. The temperature remains almost steady for 3,500 seconds and quickly dropped at 5,480 s due to the melt release. The close-up of the melt temperature history between 1,210 sec to 1,290 sec is plotted in Fig. 4. The figure indicates the plateau of the melt temperature considered as a melting period for approximately 30 sec from 1,233 sec to 1,262 sec. The average temperature is about 2,570 K. Since the melting temperature of the 70:30 corium that is used in the test is 2,810K from the phase diagram, the difference of both melting temperatures of 240 K (=2,810K-2,570K) can be considered as inaccuracy of the pyrometer due to the aerosol and other environmental effects. Therefore, actually temperature of the molten corium can be obtained by adding the difference temperature of 240K to the melt temperature measured in the test. It is important to know the melt temperature just before melt injection into the interaction chamber. We assumed that maximum temperature maintains during the melting period because the power is increased during the melting period. In Fig. 3, the maximum temperature of the melt during melting process is about 2,890K which is the average value from 2,000 sec to 2,080 sec. Therefore, the actual melt temperature is about 3,131K (2,891K+240K). The super heating of the mixture in the crucible is about 321K (3,131K -2,810K).

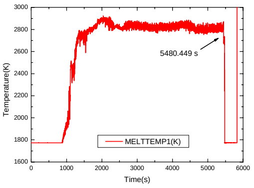

Fig. 3 Melt Temperature.

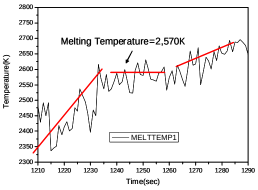

Fig. 4 Expanded Melt Temp.

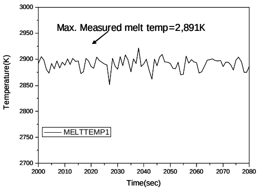

Fig. 5 Max. Melt Temp.

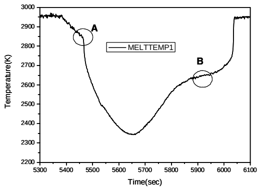

Fig. 6 Cooling and Reheating

Fig. 6 shows the melt temperature of the Case2 with cooling down and reheating during the melting process at the top of the furnace vessel. During cooling process without aerosols, the melt temperature of the point A at 5,645 sec of the Fig. 6 is about 2,850K which is the melting temperature of the composition that is used in the test. So, the measured melt temperature from the pyrometer is correct. In addition, the melt temperature is estimated during reheating of the point B in the Fig. 7, similar to the Case 1. In the Case2, the difference of both melting temperatures of 159 K (2,810K-2,651K) can be considered as inaccuracy of the pyrometer due to the aerosol and other environmental effects. The maximum temperature of the melt during melting process is about 2,948K which is the average value from 6,040 sec to 6,100 sec. Therefore, the actual melt temperature is about 3,107K (2948K+159K). The super heating of the mixture in the crucible is about 297K (3,107K -2,810K).

2.3 Melt temperature analysis

The **ME**LCOR code is used to evaluate heat loss during the relocation from the cold crucible to the intermediate catcher. The heat loss is calculated by matching the same the transient pressure curves measured in the experiment by using the MELCOR code. Since knowing the heat loss estimated by the MELCOR code, the melt temperature in the intermediate catcher can be estimated by the following energy balance equation, Eq. (1)

$$T_{ini} = T_{after} + \frac{Q_{loss}}{M_{melt} C_p} \qquad (1)$$

where, M_{melt} is melt mass, C_p is specific heat, T_{init} is the melt temperature in the cold crucible, T_{after} is the melt temperature in the intermediate catcher before melt ejection and Q_{loss} is heat loss during the relocation from the cold crucible to the intermediate catcher

Table 1 summarizes the melt temperatures in the crucible and in the intermediate catcher before melt ejection which was evaluated by two C_p values. First, the melt temperature decrease is predicted using the heat loss in the furnace vessel. In the Case 1, the melt temperature decrease in the furnace vessel is about 16K (3,131K-3,115K). In second, the melt temperature in the intermediate catcher just before melt ejection is calculated using the melt temperature, 3,115K considered heat loss in the furnace vessel. The melt temperature in the intermediate catcher just before melt ejection is 3,062K. For the Case 2, the same method is used.

Test	Vessel	T_{init}	C_p	T_{after}
		K	kJ/kgK	K
Case 1	Furnace.	3131	582	3,115
	Pressure	3115		**3,062**
Case 2	Furnace	3107	582	3,090
	Pressure	3090		**3,036**

3. Conclusions and Recommendations

The method to estimate the melt temperature is suggested in the crucible and at the melt ejection time. This kind of method is reasonable and will be useful to verify the computer code.

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[1] OECD/NEA, Agreement on the OECD/NEA SERENA Project; to address remaining issues on fuel-coolant interaction mechanisms and their effect on Ex-vessel steam explosion energetics, 2008.12.