Triggerability and Explosion Potential at Fuel Coolant Interactions

Ik Kyu Park, Jong Hwan Kim, Seong Wan Hong
Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea, 305-353
**Corresponding author: gosu@kaeri.re.kr*

1. Introduction

In the TROI experiments, melt composition affects the probability of a spontaneous explosion occurrence, but has not significant effect on the explosion work in triggered explosions[1,2]. It has been suggested that a steam explosion of the corium/water system must be suppressed due to the physical properties of corium such as high temperature, high density, multi-component oxide melt, and low thermal conductivity[3]. It was also claimed that the magnitude of the effect on the FCI results of corium/water systems is in the order of a higher density, higher temperature, and non-eutectic composition[4]. However, this is one of hypotheses to need more proofs.

The investigation based on the particle size response could be helpful to identify explosivity (triggerability and explosion potential) of corium because the particle size implies heat losses, vapor fractions, and heat contents. First, particle size distributions can be a parameter to distinguish the difference between explosive FCI and non-explosive FCI and to determine the void fraction of the mixture via interfacial heat transfer area. In the TROI tests, the steam explosion resulted in finer particle groups and less large particle groups than the quenching did. This is a confirmation of the fine fragmentation process that the large particles are transformed into fine particles by the explosion pressure propagation. Second, analyzing particle size distributions in the non-explosive TROI tests indicate that the self-triggered system has a large portion of big sized particles and the non self-triggered system has a large portion of small sized particles. But, the material difference might disappear in the triggered FCI because 80:20 corium/water exploded thermally when it triggered externally[5].

In this study, the explosivities of various melt were evaluated by calculating the heat loss of mixing particles.

2. Mathematical Model

2.1 Evaluation Tool of Heat Loss

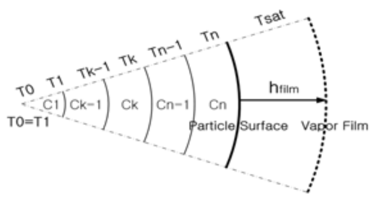

Fig.1 Evaluation Concept for Heat Loss

The heat loss from a melt particle is a measure for the triggerability of some melt/water system because the heat loss determines the vapor fraction of a melt/water mixture and the heat content of the particles, which is the resource of the steam explosion. The heat loss is a function of a melt particle size and a thermal conductivity. A single particle heat transfer model is configured, as shown in Fig. 1. The integral form of the energy balance equation of a single sphere particle without a heat source term can be described as Equation (1) for FVM numerical approach.

$$\int \rho C_p \frac{\partial T}{\partial t} dV = \int \nabla \cdot k(\nabla T) dV \qquad (1)$$

where, ρ, C_p, T, t, k represent melt density, specific heat, temperature, thermal conductivity, respectively

2.2 Analysis of Triggerablibity

An evaluation of a heat loss from a melt particle is important to estimate the void fraction of the mixture, which is more important for the triggerability, that is, spontaneous explosion. In the other hand, heat content evaluation is important to estimate the explosion potential of the mixture, which is less related to whether the triggering occurs or not.

Table 1. Calculated Heat Loss from 0.5-liter Melt

Property	Unit	Corium (80:20)	Corium (70:30)	Zirconia (100)	Alumina (100)
Conductivity	W/m·K	2.85	2.322	1.296	7.5
Diameter	mm	3.5	3.75	6	12
Temperature	K	3100	3100	3100	2600
Density	kg/m^3	7625	7263	5096	3800
Time	sec	0.51	0.5	0.5	0.5
Heat loss (0.5s)	MJ/0.5L	4.97	4.35	2.08	1.68
Heat content (0.5s)	MJ/0.5L	2.57	2.84	3.05	2.67
Total Heat	MJ/0.5L	7.54	7.19	5.13	4.35

For a heat loss from 0.5-liter melt particles, the initial condition and the calculation results are presented in Table 1. It should be noted that the mass mean particle diameters obtained from the experiments were used. The ascending order of the calculated heat loss is alumina, zirconia, 70:30 corium, and 80:20 corium, and this is consistent with the triggerability descending order: alumina, zirconia, 70:30 corium, and 80:20 corium. The order of the heat loss during a mixing, the order of the vapor fraction, and the order of the triggerability maintain this consistency.

2.2 Evaluation Tool of Heat Loss

Table 2. Calculated Remaining Heat after 0.5s Mixing

Particle Diameter (mm)	80:20 corium MJ	70:30 corium MJ	ZrO_2 MJ
8.175	0.905	0.771	1.265
5.55	0.617	0.580	0.175
3.375	0.937	1.315	0.120
1.5	0.171	0.130	0.018
0.855	0.048	0.025	0.017
0.568	0.047	0.004	0.003
0.213	0.012	0.007	0.004
Shell(5.55)	0.000	0.000	1.345
Total	2.74	2.83	2.95

Total remaining heat contents are similar each other from 2.57, 2.84, 3.05, 2.67 MJ in the Table 1, and it seems that explosion potentials are similar each other. However, the exact ascending order of remaining heat contents is 80:20 corium, Al_2O_3, 70:30 corium, ZrO_2, and the ascending order of explosion potentials should be like this. But, TROI test indicated that 80:20 corium explosion potential is not always lower than those of 70:20 corium and ZrO_2. Thus, the detailed analysis should be needed.

Table 2 provides the detailed information about remaining heat contents after 0.5s' mixing. The total particle volume was assumed to be 0.5 liters and the particle distribution was assumed to be the same as TROI 2, 11, 18. The total heat contents are similar at 2.74, 2.83 MJ, 2.95 MJ for 80:20 corium, 70:30 corium, ZrO_2, respectively. Their differences get smaller, but the order is the same from the values of Table1. Remaining heat contents of the big sized particle group, however, are 1.52 MJ, 1.35 MJ, and 1.43 MJ for 80:20 coirum, 70:30 corium, and ZrO_2, respectively. The order of the remaining contents is not the same as that of average values or total values. The ascending order of explosion potentials is 70:30 corium, ZrO_2, 80:20 coirum, and this is an explanation that 80:20 corium showed slight larger explosion work than 70:30 coirum or ZrO_2 with an external triggering event. It might be said that the explosion potential is the remaining heat contents of the big sized particle group.

The explosivity, in other words, triggerability and the explosion potentials can be evaluated by the particle size distribution and the thermal conductivities in brief. The particle size distributions are determined by mixing process which is governed by hydro-dynamic conditions and several physical properties such as density and surface tension, and then the breakup model and these properties are very important for estimating steam explosion work.

3. Conclusions

The single particle heat transfer calculations reveal that reliable values for a thermal conductivity and a particle size can provide the order of the triggerability and explosion potential of the melt/water system. A system having a small particle size and a large thermal conductivity induces a larger heat loss and a more voided mixture, which means a less triggered system. A less triggered system does not mean having a less explosion potentials because the big sized particle group, persevering its initial heat well, is the energy source of a steam explosion. The remained energies in big size particle group for 80:20 corium, 70:30 corium, and ZrO_2 are similar to each other in TROI experiments. The particle size and thermal conductivity seem to be the dominant factors in evaluating an explosivity. Thermal conductivity should be properly considered in a fuel and coolant heat transfer model. The particle size estimation is difficult due to an incomplete understanding of the break-up mechanism and an incomplete quality of physical properties such as surface tension. In order to implement a reliable analysis for a fuel coolant interaction, the uncertainties of a break-up model and the values of the physical properties such as surface tension should be resolved in the future.

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