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Analyses of the Particle Size Distributions from TROI FCI Tests

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1. Introduction

Sometimes fuel coolant interactions are accompanied by destructive shock waves generated from a rapid heat transfer[1]. So, a lot of experimental and analytical researches on steam explosions have been performed. The experimental researches cover small-scale experiments, medium scale experiments, and experiments with a real core material[2,3]. There exists several steam explosion analysis codes such as ESPROSE.m, IFCI, MC3D, TRACER-II, TEXAS-V, which are different from each other in their dimension, breakup model, and fragmentation model[4]. Thus, their results do not agree with each other, and a difference in their breakup models might be one reason for this disagreement.

The TROI[5,6] experiments were carried out to provide experimental data for a proper estimation of a steam explosion work. The explosion work can be characterized by the explosion pressure wave, and the mixture condition can be characterized by a particle size distribution. Thus, the TROI tests were analyzed in view of a particle size response for various types of fuel coolant explosions.

In this study, the final particle size distributions induced by both explosive FCI and non-explosive FCI were discussed. This analysis could indicate a difference between an explosive FCI and a non-explosive quenching. Also, the mixing size of the particles to participate in a steam explosion and the fine particle size produced from a steam explosion could be defined in the TROI test.

Considering the several findings in the TROI experiments, the parametric effects on the particle size were analyzed by using the non-explosive TROI tests. This analysis on the particle size response can provide an understanding about the relationship among the initial condition, a mixing, and an explosion.

2. Findings in TROI Experiments

One of the findings from the TROI experiments is that the results of the fuel coolant interaction are strongly dependent on the composition of the corium, which is composed of UO_2, ZrO_2, Zr, Steel[7]. Prototypic corium generally used in the FCI experiments is a mixture of 80 % of UO_2 and 20% of ZrO_2. In the TROI experiments, a typical 80:20 corium was not apt to create spontaneous steam explosions, while 70:30 corium created spontaneous steam explosions probabilistically. 100 % ZrO_2 was almost apt to create a steam explosion if the water subcooling was enough. Even though just being conducted once, 87:13 corium and 49:51 corium did not induce spontaneous steam explosions.

Another finding from the TROI experiments is that the results of the fuel coolant interaction tests are changed as the initial water depth is changed. Water area effect in the TROI experiments is not clear because tests under 0.071 m^2 in water area, 67cm in water depth, and 70:30 corium were not conducted. Obvious thing is that 0.071 m^2 in water area does not increase the steam explosion work by more than 0.283 m^2 when compared to the tests under 95 cm and 130 cm in water depth.

For an application of the parametric tests, the initial conditions, a mixing, and an explosion should be related to each other. In the next chapter, the TROI tests were analyzed in view of a particle size response to various types of fuel coolant tests. This could provide an understanding about the relationship among the initial condition a mixing and an explosion.

3. Analyses of Particle Size Distribution of TROI Tests

The comparisons between the quenching and steam explosion cases are presented in Table 1. Two FCI tests using ZrO_2 are shown in comparison A of Table 1. One resulted in a quenching and the other resulted in a steam explosion. The distribution of the final particle size is quite different from each other mainly due to the steam explosion. The mass of the particles above 6.35 mm in diameter is 2 kg(36.4 %) and the particle mass under 0.71mm in diameter is just 0.04 kg(0.7 %) in TROI-2, while the particle masses in TROI-4 are 0.18 kg(4.3 %) and 0.26 kg(6.1 %), respectively.

Two tests using 70:30 corium are shown in comparison B of Table 2. The initial conditions of TROI-11 and TROI-13 are the same or similar for all the controllable coolant and fuel conditions. However, a steam explosion occurred in only TROI-13. The mass of the particles above 4.75 mm in diameter is 2.855 kg(31.9 %) and the particle mass under 0.71 mm in diameter is just 0.09 kg(0.9%) in TROI-11, while the particle masses in TROI-13 are 0.865 kg(11.2 %) and 2.43 kg(31.4 %), respectively.

The particle group of above 6.35 mm in diameter must be the energy source of the steam explosion, and the particle group of 0~0.710 mm in diameter must be the product of the steam explosion.

Table 1. Comparison between quenching and explosion

TROI Test #	Unit Date	Compare A		Compare B	
		2	4	11	13
Corium	w/o	0/100	0/100	70/30	70/30
explode		NO	SE	NO	SE
Total	kg	5.50	4.216	9.23	7.735
>6.35mm	(%)	(36.4)	(4.3)	(16.1)	(8.0)
4.75~6.35	(%)	(12.2)	(26.5)	(14.8)	(3.2)
2.0~ 4.75	(%)			(52.0)	(34.6)
1.0~2.0	(%)	(4.5)	(12.8)	(13.6)	(15.8)
0.71~1.0	(%)			(2.6)	(7.0)
.425~ .71	(%)	(0.7)	(6.1)	(0.4)	(12.5)
<0.425	(%)			(0.5)	(18.9)
Shell>50	(%)	(46.2)	(32.3)	(0)	(0)
Sh 10-20	(%)	(0)	(18.0)	(0)	(0)

Table 2 shows the TROI experimental results ordering by the composition; TROI-2, TROI-11, TROI-18, TROI-29. The difference in the particle size response between the ZrO_2 system and the corium system is a major group of the particles. The large sized particle group(above 6.35mm) occupies 36.3 % of the total particle mass in the ZrO_2 system (TROI-2), but the relatively small sized particle of 2-4.75mm in diameter occupies 38%-52% in the corium system (TROI-11, 18, 29). Considering that the large sized particle group above 6.35mm in diameter is the major contributor to the steam explosion energy as mentioned in above, the ZrO_2/water system seems to be more explosive than the corium/water system. This particle behavior accords with the TROI experimental results.

Table 2. Composition Effect On Size (Quenching)

TROI Test #	Unit	2	11	18	29
UO_2/ZrO_2	w/o	0/100	70/30	78/22	50/50
Total	kg	5.50	9.23	9.055	11.510
>6.35mm	(%)	(36.3)	(16.1)	(18.4)	(7.9)
4.75~6.35	(%)	(12)	(14.8)	(15.6)	(10.3)
2.0~4.75	(%)		(52.0)	(38.2)	(38)
1.0~2.0	(%)	(5)	(13.6)	(17.6)	(19.5)
0.71~1.0	(%)		(2.6)	(4.9)	(6.7)
.425~.71	(%)	0.04 (0.7)	(0.4)	(4.5)	(8.9)
<0.425	(%)		(0.5)	(0.8)	(8.7)
Shell	(%)	(46)	(0)	(0)	(0)

The difference in the particle size responses of 70:30 corium and the other corium is a portion of the fine particle group below 0.71 mm. That is the fine particle group in the 70:30 corium system occupies only 0.9 % (TROI-11), which is nearly the same as the ZrO_2 system. The portions of the fine particle group in the 80:20, 50:50, 87:13 corium are 5.3 %, 17.6 %, 11.7 %, respectively.

This difference could be one fact why the probability of a steam explosion is higher in the ZrO_2, 70:30 corium system than in the 80:20 corium. The fine particle group seems to prevent a spontaneous steam explosion by raising the void fraction and/or by quenching the fuel melt mainly due to an increased heat transfer area.

4. Conclusions

The particle size distribution might be an important parameter for explaining a steam explosion occurrence or steam explosion strength. An increase of the large particle portion and a decrease of the fine particle portion in the mixing stage could result in an explosion and its opposite could result in a mild quenching. A particle size distribution is affected by the initial conditions such as the melt composition, water depth, and water area, and the fuel coolant interaction is varied by the initial conditions. Thus, this point should be properly considered in a steam explosion model during a reactor safety analysis.

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