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Material Effects on the Result of Fuel Coolant Interactions

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1. Introduction

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 UO2, ZrO2, Zr, steel[1]. It has been suggested that the corium/water system must be suppressed by the explosive reaction due to its properties such as a high temperature, high density, multi-component oxide melt, and low thermal conductivity[2]. It was also claimed that the magnitude of the effect on the FCI results are in the order of a higher density, higher temperature, and a non-eutectic composition[3].

In order to understand the mechanism of this material effect on fuel coolant interactions and to contribute to reactor safety analyses, we need to connect the material properties, mixture conditions, and explosion works. The explosion work can be characterized by the explosion pressure wave, and the mixture condition can be characterized by the volume fractions and particle size distributions. In this study, the mechanism for a material difference affecting on the result of a fuel coolant interaction was evaluated through a TEXAS-V[4] simulation, an analysis of non-explosive TROI tests, and a single sphere film boiling model.

2. Sensitivity Study on Materials at Steam Explosions by Using TEXAS-V

The TROI experimental results, and the TEXAS-V calculation show that the void fraction of a mixture is the key parameter to determine the explosive strength of the fuel coolant interactions. The fuel diameter could be a dominant factor to control the void fraction by considering the TROI results[5] and TEXAS-V calculation.

However, the calculation for the alumina/water system shows that another important factor to control the void fraction exists. In Figs 1,2 the void fraction is high and the explosion pressure is low in the alumina/water system, even though the particle size in this system is not smaller than that in the zirconia/water system and the initial alumina temperature is lower than the zirconia temperature. This indicates that another factor except for the particle size plays some role in determining the void fraction.

We also note that this calculated alumina particle size and the calculated explosion pressure are smaller than those in the experimental results. This means that there are some uncertainties in the current breakup model or the value of the breakup-related physical properties. This should be carefully investigated, but it is beyond the scope of this study at present.

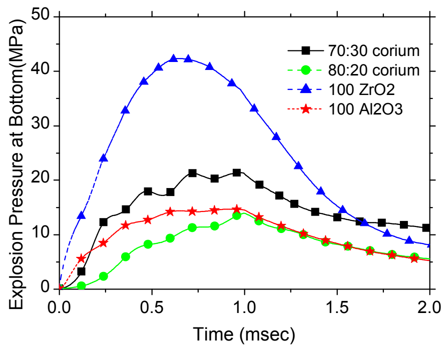

Fig. 1. Calculated explosion pressure for various materials

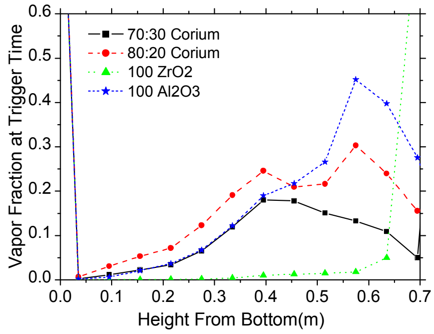

Fig. 2. Calculated vapor fraction for various materials

3. Analyses of Particle Size Distribution of TROI

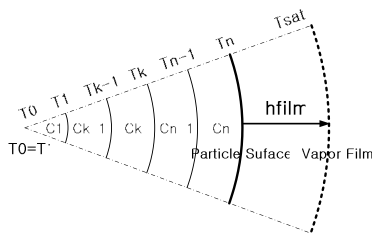

Fig. 3. FVM concept for a single sphere film boiling

The heat loss from a melt particle could be a measure for the explosivity of some melt/water systems because the vapor fraction means the heat loss from a melt particle. A single particle heat transfer model could be configured as Fig. 3.

The integral form of an energy balance equation for a single sphere particle without a heat source can be described as Equation (1).

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

Where, $\rho, V, C_p, T, k,$ and t represent the density, finite volume, specific heat, temperature, conductivity, and the time. All other variables except for the diameter can be intuitionally determined.

Past works[6] show that the particle size is highly dependent on the material type; a large particle size of alumina, zirconia, 70:30 corium, 80:20 corium seems to be 10~30 mm, ~10 mm, ~6 mm, ~ 6mm, thus the particle size of them could be defined as 12 mm, 6 mm, 3.5 mm, 3.75mm, respectively by considering an experimental mass mean diameter, a large particle size distribution.

The initial condition and the calculation results are presented in Table I. It should be noted that the mass mean particle diameters obtained from experiments were used. The order of the calculated heat loss is alumina < zirconia < 70:30 corium < 80:20 corium, and this is consistent with the explosive order, alumina > zirconia > 70:30 corium > 80:20 corium. The order of the heat loss during a mixing, the order of the vapor fraction, and the order of the explosivity maintains this consistency.

Table I: Calculated Heat Loss by Using a Single Sphere Film

Property	Unit	Corium (80:20)	Corium (70:30)	Zirconia (100)	Alumina (100)
Conductivity	W/m·K	2.84	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 (0.25s)	MJ/0.5L	3.83	3.32	1.58	1.01
Heat loss (0.5s)	MJ/0.5L	4.97	4.35	2.08	1.43
Total Heat	MJ/0.5L	7.54	7.19	5.13	3.21

4. Conclusions

Considering the past works, following items can be elucidated: Corium/water system is less explosive than alumina/water, and a large voided mixture is a reliable reason. A high temperature, fine breakup, and a hydrogen generation could result in a highly voided mixture.

From the TROI experiments, following items are induced: The material and/or composition difference have an effect on the results of the fuel coolant interactions. The zirconia, 70:30 corium, and 80:20 corium are orderly explosive. The particle size responses for the TROI parametric tests showed that a different material resulted in a different particle size distribution. An increase in the large particle portion and a decrease in the fine particle portion at a mixing stage could result in an explosion and its opposite could result in a mild quenching.

From the TEXAS-V calculation, next items are extracted: The material effect on the steam explosions was caused by a void fraction difference, which was driven by a particle size difference. The calculation for the alumina/water system indicates that the conductivity has an inversely proportional effect on the explosivity.

From the single particle heat transfer calculation, the following next items are considered: A reliable conductivity and particle size can provide us with the order of the explosivity of the melt/water system. A system having a small particle size and a large conductivity induces a larger heat loss and a more voided mixture, which means a less explosive system.

ACKNOWLEDGMENTS

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