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Parametric Calculations for Subcooling and Triggering Timing Effects in a TROI Test

I. K. Park*, J. H. Kim, B. T. Min, S. W. Hong
Korea Atomic Energy Research Institute,1045 Daedeok-daero, Yuseong-gu, Daejon, 305-353,Korea
** Corresponding author: gosu@kaeri.re.kr*

1. Introduction

The major issue of a steam explosion is to understand why the fuel coolant interactions (FCIs) of a corium melt is lower energetic than those of an alumina melt. Among all the different possibilities, the effect of a partial solidification, a higher void, and a less fine fragmentation rate due to material characteristics were envisaged as a major potential effect for a weaker explosion. It should be noted that there should not be any confusion between the energetic characteristics and the occurrence of a spontaneous steam explosion.

A partial solidification and a higher void are related to the major mixing process: the jet breakup, the heat transfer, and the vaporization. Then, the mixing process is governed by the initial condition such as a subcooling and the type of fuel material and is limited by a triggering time. Thus, a subcooling, a type of fuel material, and a triggering time can become major parameters to control the steam explosion work.

The results TROI experiments indicate that the results of the fuel coolant interaction (FCI) 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].

It is obvious that the type of fuel material affects the results of the FCIs and that the material effect exerted on the FCI process by the void, the solidification, and material-based fragmentation mechanism[4]. But, the problem is that it is not clear what among these three factors of a void, a solidification, and a suppression of a fragmentation is the key for the material effect. Thus, the approach through a subcooling and a triggering time except the type of material might be an easier path for the first step towards the major issue of a steam explosion. Meanwhile, the experimental investigation is too expensive and too difficult to observe the details though it must be a good tool for this study.

In this study, a sensitivity study on a steam explosion was conducted for a subcooling and a triggering time among the three major parameters. The void fraction, the fuel temperature, and the explosion pressure will be the factors to be analyzed. This study was conducted by using the MC3D code[5].

2. Input Model

The configuration of the geometrical condition are presented in Figure 1, in which the axi-symmetric cylindrical coordinate was adapted to the TROI test facilities[6].

A test condition by considering the prototypical severe accident condition and the limitation of the TROI test facilities was set up: pressure of 0.4 MPa, liquid temperature of 293 K, vapor temperature of 312.19 K fuel temperature of 3100 K, jet temperature of 3100 K, water depth and diameter of 1 m and 60 cm, melt free fall of 1m, melt mass of 20 kg

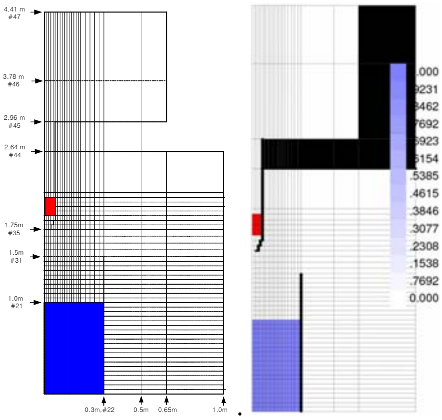

Fig. 1. Calculated explosion pressure for various materials

3. Mixing Calculation

The melt jet progression is presented as the time-dependent position from the bottom and the mixture behavior at 0.8215 sec in Figure 2. The fuel arrived at the bottom at 0.8215 sec after its pouring. The fuel fell from the release nozzle (2 m) to the surface (1 m) with nearly a constant speed of 5 m/s. The melt falling speed become lower at 2.6 m/s from the surface (1 m) to 0.5 m due to the jet breakup. The falling speed maintains a constant value of 1.6 m/s.

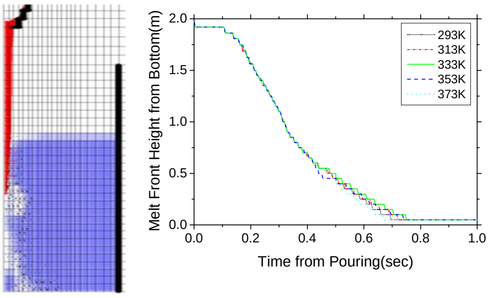

Fig. 2 FVM concept for a single sphere film boiling

The radially-averaged axial void fractions for the largest and smallest subcooled cases are presented in Figure 3. The legends mean the time after a pouring. The axial void fraction of the lower subcooling case is much bigger than those of the higher subcooling case. The sauter mean diameter of Figure 4 indicates that the void fraction differences mainly resulted from the lower evaporation and the higher condensation by the subcooling. The sauter mean diameter differences are not so big and the fuel is cooled more for a larger subcooling case. It must be noted that the mixing results at 0.82 sec are meaningful in this discussion because the melt bottom contact is a proper time for an explosion triggering.

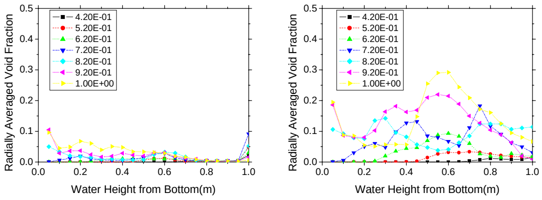

Fig. 3 Axial void for 293 K(δ 123K), 373 K(δ 43K)

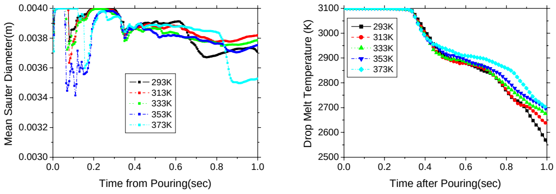

Fig. 4 Time-dependent Sauter mean diameter and the melt drop temperature for 5 subcooling cases.

3. Explosion Calculation

The explosion calculations were conducted by using 5 triggering times. The explosion pressures for the higher and lower subcooling cases are compared in Figure 5. The explosion pressures of a higher subcooling case are twice as large as those of a lower subcooling case.

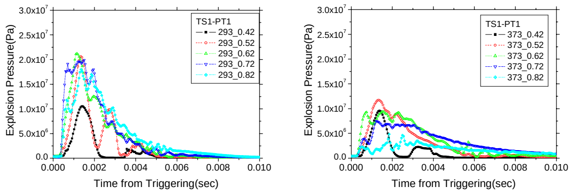

Fig. 5 Explosion pressure profiles for 293 K, 373 K

The explosion impulses of Figure 6, which can be calculated by integrating the explosion pressure for the time, show the same pattern as the explosion pressure of Figure 5. This result in which the explosion in the higher subcooling case are more energetic is mainly governed by the lower void fraction: in the figure 7, the fragmented masses are not really different for each case. But, it should be noted that the restriction of a fragmentation by a solidification was not considered. Even though its effect may not be large, it might reduce the explosion work for a higher subcooling case because the melt drop temperature is lower as in Figure 4.

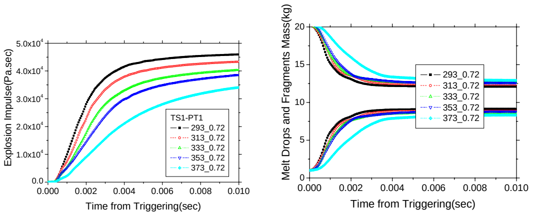

Fig. 6 Explosion impulse by 0.72 s triggering and the masses of melt drops and fragments.

4. Conclusions

Parametric steam explosion calculations were conducted for various subcoolings and various triggering times. A higher subcooling and a triggering right after a melt bottom contact resulted in a more energetic steam explosion. The role of the higher subcooling is in a higher voided mixture and a lower melt temperature. The melt temperature does not have an effect on the steam explosion work. The reason could be from the solidification model. The effects of the void and the triggering time on the steam explosion work are clear now. An investigation on a solification should be conducted further for evaluating the subcooling effect on the steam explosion work.

ACKNOWLEDGMENTS

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REFERENCES

[1] J.H. Kim, I.K. Park, B.T. Min, S.W. Hong, J.H. Song, and H.D. Kim, An Effect of Corium Composition Variations on Occurrence of a Spontaneous Steam Explosion in the TROI Experiments, Proceedings of NUTHOS-6, Nara, Japan, Oct. 4-8, 2004.

[2] T.N. Dinh, Material Property Effect in Steam Explosion Energetics: Revisited, Proceeding of NURETH-12, Pittsburgh, USA, Sep. 30-Oct. 4, 2007.

[3] T.N. Dinh, A.T. Dinh, J.A .Green, and B.R. Sehgal, An Assessment of Steam Explosion Potential in Molten-Fuel-Coolant Interaction Experiments, Proceedings of ICONE-6, San Diego, USA, May, 1998.

[4] I.K. Park, J.H. Kim, S.H. Hong, B.T. Min, S.W. Hong, J.H. Song, and H.D. Kim, An Investigation of the Particle Size Responses for Various Fuel-Coolant Interactions in the TROI Experiments, Nuclear Technology, 161, pp.45-56, 2008.

[5] R. Meignen, Status of the Qualification Program of the Multiphase Flow Code MC3D, Proceedings of ICAPP'05, Paper 5081, Seoul, Korea, May 15-19, 2005.

[6] I.K. Park, J.H. Kim, S.W. Hong, B.T. Min, H.Y. Kim, and J.H. Song, Quick Look Report for SERENA program, TROI-QLR-014, Rev.01, Test No.: TROI-13, June 17, 2003.