An Evaluation of the Steam Explosion Model of MC3D Code

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1. Introduction

A computational model must be a necessary tool to analyze the safety of the nuclear reactor for a steam explosion during a postulated severe accident with. Several computational codes for a steam explosion has been developed based upon the experimental work and contributed to the safety analysis of the nuclear power reactor. One of the great contributions of the computational codes is giving the basis on the consensus that the in-vessel steam explosion steam explosion would not challenge the integrity of the vessel and the containment [1]. The ex-vessel explosion, however, cannot be excluded from the factor to threaten the integrity of the cavity and more the reactor vessel. The results of steam explosion experiments indicate that the subcooled water under a low pressure might be a good environment to make a strong steam explosion [2]. Furthermore, the calculation results for evaluating ex-vessel steam explosion work are too scattered each other [1]. Thus, the ex-vessel explosion is still remained as a resolved issue. These uncertainties comes from the fact that many of the fuel coolant interaction (FCI) processes are not fully understood which is especially true for the exotic parameter range encountered in nuclear safety problems. Therefore there are a variety of models for the important phenomena of FCIs.

Thus, the uncertainties, which is included in the computational codes in the form of the model or the input parameter, should be are defined or fixed against the experiments. The FCI's own models such as film boiling heat transfer, breakup, fragmentation and two-phase related models such as condensation, drag, interfacial heat transfer, etc should be separately validated for the thermal-hydraulic condition of the steam explosion situation. But, it is impossible due to the very ultimate thermal-hydraulic condition such as 3000-K corium and 10-MPa shock wave. Most thermal-hydraulic models, which are developed within the reachable conditions, are extrapolated for simulating a steam explosion. The developed computational codes can't be validated intensively. The well defined integral steam explosion, therefore, was the only method to evaluate the computational code. Fortunately, the past researchers divided a steam explosion process into 3 steps: mixing, triggering, explosion. Moreover, it is reliable opinion that the triggering event will not affect the explosion work if the mixture condition is the same. Thus, the experimental and analytical studies for the steam explosions can be divided into mixing and explosion and done systematically even though explosions always include the mixing process.

In this paper, the post-calculation of TS-2 TROI test is presented and the evaluations of the steam explosion models are discussed briefly. All the calculations are done by using MC3D code in this paper [3].

2. Input Model and Mixture

A test condition by considering the prototypical severe accident condition and the limitation of the TROI test facilities was set up: pressure of 0.22 MPa (saturated at 396.7 K), liquid temperature of 334 K (62.7° subcooled), jet temperature of 3063 K, water depth and diameter of 1 m and 60 cm, melt free fall of 1 m, melt mass of 12.5 kg. The configuration of the geometrical condition and the pre-mixture conditions are presented in Figure 1, in which the axi-symmetric cylindrical coordinate was adapted to the TROI test facilities [4]. The fuel jet arrives at 10-cm elevation at 0.88 second after the injection was started in the calculation. It is a little faster than that of experiment: the fuel jet arrives at 40-cm elevation at 0.88 second. The calculated average vapor volume fraction is 0.06 at that time, which is similar to 0.04 of the TS-2 test. The cover pressure buildup, the released melt mass, the particle mass, and the Sauter mean diameter are 0.008 MPa, 12.6 kg, 7.4 kg, 3.3 mm at 0.88 second.

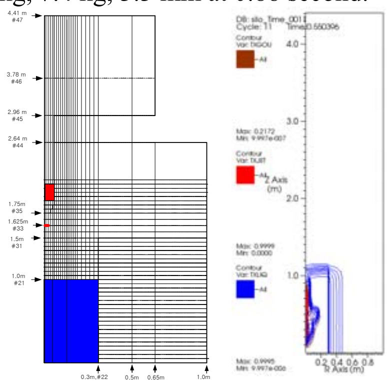

Fig. 1 Geometrical Condition and Pre-mixture at 0.88 s.

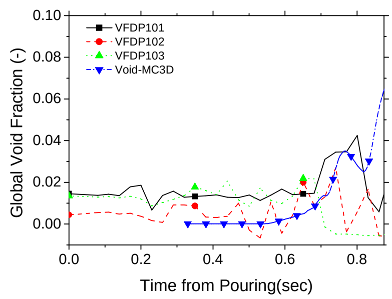

Fig. 2 Measured and Calculated Vapor Volume Fraction.

3. Sensitivity Study for Minimum Bubble Diameter

In the previous TS-1calculation [4], the explosion pressure peak and the explosion pressure impulse cannot be fitted simultaneously by tuning the fragmentation model. If we increase the fragmentation rate to fit the explosion pressure peak, the explosion pressure impulse become much bigger than the measured impulse. In this study, the minimum bubble diameter was chosen to adjust the explosion pressure peak and the explosion pressure impulse simultaneously. The comparison between the measured explosion force and the calculated explosion force are presented in Figure 3. The Figures indicate that the time integration of the force can be reduced, maintaining the force peak. 0.25 mm is a proper minimum bubble diameter for the TS-2 test.

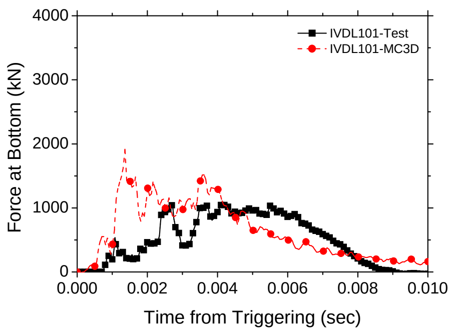

Fig.4 Measured and Calculated Force (D_{min}=0.25mm).

4. Explosion Calculation

The comparisons of the pressure and the pressure impulse are presented in Figure 5 and Figure 6. The calculated pressure and the pressure impulse can be fit to the measured data simultaneously with the minimum bubble diameter of 0.25 mm.

5. Conclusion

The diameter of the first particles by Kelvin-Helmholtz induced jet breakup is set to 4 mm. The Rayleigh-Taylor induced fragmentation model is used for secondary break-up of the fuel particles. The standard two-phase flow mapping by 0.3 and 0.7 of vapor fraction, the Dhir-Purohit film-boiling model are used. The minimum bubble diameter is set to 1.16 mm for the mixing. The melt jet was injected with 2.5m/s-velocity and 5-cm diameter at 162.5-cm elevation. The thermal and hydrodynamic fine fragmentation models were used. The diameter of the fine fragments is set to 100 μm. The minimum bubble diameter during explosion was set to 0.25 mm. The MC3D with these models simulate TS-2 test properly. The things that should be further assessed are the melt jet progression, and the first drop size.

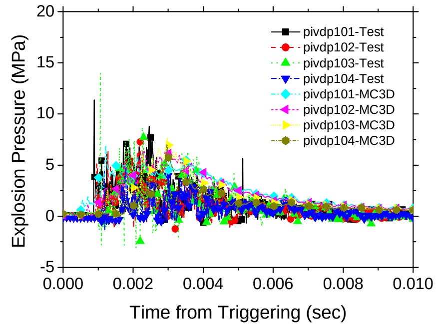

Fig. 5 Measured and Calculated Pressure (D_{min}=0.25mm).

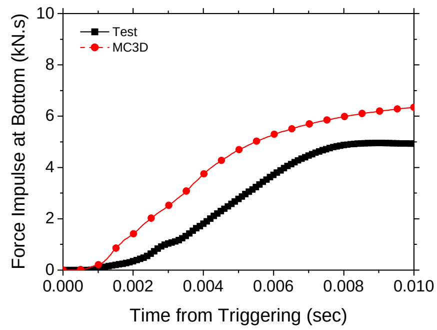

Fig. 6 Measured and Calculated Impulse (D_{min}=0.25mm).

ACKNOWLEDGEMENTS

This work was sponsored by OECD/NEA SERENA project. This work was also supported by Nuclear Research and Development Program of National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).(grant code: M M20702040004-08M0204-00410):

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