A Coherent Steam Explosion Analysis Methodology Using TEXAS-V Code

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1. Introduction

The computational model for the steam explosion phenomena [1] should be able to describe the multi-phase, multi-dimensional, and multi-component phenomena at different length scales. The name of the computational model is TEXAS-V and it is widely used for the analysis of the steam explosion load during a hypothetical severe accident in a nuclear power plant, where a molten core material at a very high temperature is in contact with water. The objective of the research is to pursue a converged understanding of the fundamental physics of the steam explosion phenomena, which are necessary for the prediction of the steam explosion load on a reactor scale and identify the shortcomings of the existing models and experimental data [2].

2. The Evaluation of the Premixing Model

The two break up models implemented in TEXAS-V are used in the analysis. It was shown that while the old break up model based on the RTI and the new break up model, which has a more mechanistic break up mechanism including the RTI, BLS, and KHI, do not show much difference for the simulation of FARO L-14[3], but show a quite different behavior in the case of FARO L-28 as shown in Fig.1.

It was shown that the computational model was adequate enough to predict the jet break up model and the thermal hydraulic response during the premixing phase for a transient with a rather short pour and at a high pressure. However, it was necessary to increase the effectiveness of the Kelvin Helmholtz instability substantially to match the L-28 pressure.

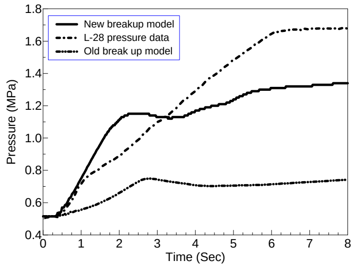

Fig. 1 L-28 Simulation Using TEXAS-V

3. The Evaluation of Explosion Model

A brief summary of the results of the analysis for the explosion phase only is provided in Table 1. TEXAS-V computer code has a fragmentation model by Tang [4] during the explosion presented as

$M_f = C_{fr}\ m_p(P-P_{th})^{0.5}/(\rho_c R_p^2)^{0.5} g(\tau)F(\alpha)$

Based on Tang's analysis[4], the standard values of C_{fr}=0.002 anτ = 1 ms were chosen for the simulation of KROTOS-44. The explosion model for FARO L-33 simulation is the same as those of the KROTOS 44 simulation. The calculated pressure is ten times bigger than the measured pressure.

The parameters for the explosion model for TROI-13 and TROI-34[5,6] simulation were the same as those used in the simulation of the KROTOS-44. It is shown that the pressures are in the same order as those of the experiments.

These findings are quite inconsistent with those of FARO L-33. The main difference is the fuel fraction. The fuel fraction is in an order of a magnitude smaller than that of FARO L-33. The low fuel fraction could have resulted in a low dynamic pressure. It can be claimed that the TEXAS-V computer code predicts the dynamic pressure in the same order of a magnitude for the experiments at a very low fuel fraction.

4. Reactor Scale Steam Explosion Simulations

The steam explosion model constants were evaluated from the pre-mixing and the explosion calculations. 0.01 and 0.2 would be the proper value of the breakup constant and thick film criterion for K-H instabilities, respectively. The standard values of C_{fr}=0.002 anτ = 1 ms suggested by Tang[4] were fixed and the fragmented size of R_f=100 μm was evaluated for the corium tests.

Two basic points should be considered in the steam explosion calculations by TEXAS-V. One is the breakup model. The other point is the calculation cell area because TEXAS-V code is one-dimensional and the actual steam explosion phenomena would be 2-dimensional. Thus, the 3 calculation sets were defined as mixing zone sizes and the breakup models in the Table 2.

In CASE1, the fuel melt is poured into 4m, 50K subcooled water pool of 5.5m diameter under 0.2 MPa. The free fall of the fuel melt is 1m. This explosion pressure wave is stronger than that of bottom triggering, and the impulse load on the bottom comes to 70 kPa.sec.

CASE2 is different in the size of mixing zone or calculation area from CASE1. The mixing zone diameter in CASE1 is 5.5 m and that in CASE2 is 3.85 m. The explosion peak pressure and the impulse on the bottom are bigger at 94 kPasec and 70 MPa than those of CASE2.

CASE3 is different in the breakup model from CASE1. The breakup in CASE1 occurs by only Rayleigh-Talyor instabilities and that in CASE2 does by three mechanisms. The explosion peak pressure and the impulse on the bottom is bigger at 95 kPasec and 180 MPa than those of CASE1.

4. Conclusion

The analyses in this section focused on the evaluation of the pre-mixing model and the explosion model separately. The evaluated TEXAS-V model were consistently used for the real scale plant's steam explosion calculation, and the center-triggering of 10MPa made the steam explosion with the pressure peak of 40MPa and the impulse of 70kPa.sec.

The effect of the reaction zone size was minor, but the change to old breakup model highly affects the steam explosion work. The large difference would be induced by the high void fraction due to the small size particles from the Kelvin-Helmholts instabilities of the new breakup model.

However, the present analyses demonstrates that the TEXAS-V could be a promising tool for predicting the steam explosion load on a reactor scale, as the analyses results with the default parameter setting predicted the experimental results reasonably well.

ACKNOWLEDGMENTS

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Table 1. A Summary of the Analysis Results for the explosion phase only

Parameter	FARO L-33	KROTS-44	TROI-13	TROI-34
Explosion only	Yes	Yes	Yes	Yes
Melt fraction/mass (kg)	0.026/25	0.026/1.5	0.000636/1.14	0.000636/1.14
Explosion Model Constants	R_f=20μm, C_{fr}=0.002 T_{fr}= 1 ms	R_f=20μm,C_{fr}=0.002 T_{fr}= 1 ms	R_f=100μm, C_{fr}=0.002 T_{fr}= 1 ms	R_f=100μm, C_{fr}=0.002 T_{fr}= 1 ms
Calculated Pressure (MPa)	100	75	3	25
Fuel Diameter (mm)	3.6	15	3	3
Pre-mixture Height (m)/Width(m)	1.7/0.3	0.75/0.2	0.7/0.2	0.7/0.2
Void fraction	0.05, uniform	0.09	0.04,uniform	0.04,uniform
Trigger	14MPa/14 μs	14 MPa/ 1ms	Spontaneous	10MPa/0.2 ms

Table 2. Major Modeling Parameters(Water level in CASE2 is higher 0.4m to high void fraction.)

Parameter	Case 1	Case 2	Case 3
Break up model	New, L-14	New, L-14	Old
Size of Mixing Zone (m)	5.5	3.85	5.5
Jet Diameter	0.5	0.5	0.5
Rf (m), Cfr	1.E-4, 0.002	1.E-4, 0.002	1.E-4, 0.002
Trigger time (s)	0.9657	0.9743	0.9657
Bottom contact (s)	0.9657	0.9743	No contact
Fuel Mass in water (kg)	4710	5240	4710
Trigger Magnitude (MPa)	10	10	10
Impulse (KPa*s)	63	94	180
Peak Pressure (MPa)	40	70	95