Transient Simulations of a Core Concrete Interaction Test

Hwan Yeol Kim and Jong Hwa Park
Korea Atomic Energy Research Institute,150 Deokjindong,Yuseonggu,Daejeon
hykim1@kaeri.re.kr, jhpark3@kaeri.re.kr

1. Introduction

In the OECD/MCCI project scheduled from 2002. 1 to 2005. 12, a series of tests was performed to secure the data for cooling a molten core spread out at the reactor cavity and for the 2-D long-term core concrete interaction (CCI). The tests included not only separate effect tests such as a melt eruption, water ingression, and crust failure tests with a prototypic material but also 2-D CCI tests with a prototypic material under dry and flooded cavity conditions.

This paper deals with the transient simulations for the CCI-2 test[1] by using a severe accident analysis code, CORQUENCH Version 3[2], which was developed at Argonne National Laboratory (ANL). The CORQUENCH Version 3 has been structured to incorporate phenomenology that is a key to analyzing debris cooling behavior, including bulk cooling, melt eruption model, and water ingression cooling mechanisms. The simulation results were compared with the previous results obtained by using MELCOR 1.8.5[3].

2. CCI Simulations

2.1 Brief Description of CCI Test

As shown in Figure 1, the CCI test facility consists of a test section, a power supply for a Direct Electrical Heating (DEH) of the corium, a water supply system, two steam condensation (quench) tanks, a ventilation system to complete filtration and exhaust the off-gases, and a data acquisition system. The test section is about 3.4 m tall with a square internal cross-section of 50 cm x 50 cm.

Temperatures of both the basemat and sidewalls of the test section are measured with multi-junction Type K thermocouple assemblies to determine the 2-D ablation profile as a function of time. Melt generation is achieved through an exothermic chemical reaction and DEH is supplied to the melt to simulate a decay.

2.2 CORQUENCH Model

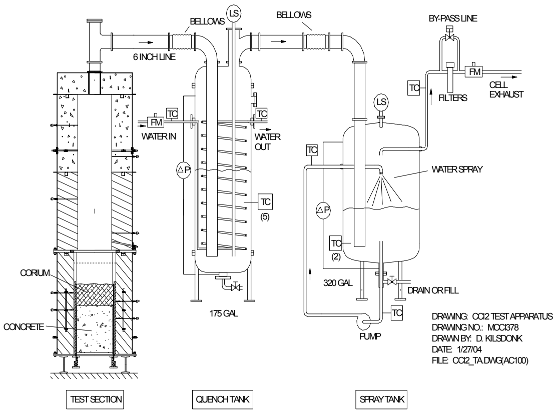

Fig. 1 Schematic of CCI test facility

When the melt/water interface temperature falls below freezing temperature, a stable crust may form. If a crust has an insufficient strength, then thin crust segments will form, but the segments will be continuously broken up by the sparging gas and mixed back into the melt. The correlation for the critical superficial gas velocity below which a stable crust forms can be estimated from the following correlation:

$$j_{g,crit} = \frac{0.445 R h_m (T_m - T_f)}{\delta_{crit}\rho_{cr}\Delta e_{cr}\left\{\dfrac{k_{cr}(T_f - T_{sat})}{\delta_{crit} h_m (T_m - T_f)}\ln\left[\dfrac{1}{1-\xi}\right] - 1\right\}},$$

Water ingression can commence if a film boiling has broken down and the coolant is in sustained contact with the crust. In terms of thermal-hydraulic results, the main finding from the water ingression tests was a correlation for the dryout heat flux, $q''_{dry}(P,\chi^{m}_{con})$, as a function of system pressure and corium concrete content. This correlation is in the form:

$$q''_{dry} = C\left(\frac{h_{lv}(\rho_l - \rho_v)g}{\nu_v}\right)^{5/13}\left(\frac{N k_{cr}^2 (\Delta e_{sat})^2}{c_{cr}\Delta e_{crack}}\right)^{4/13}\left(\alpha_{\exp}\left[T_{sol} - \left(T_{sat} + \frac{\sigma_y}{\alpha_{\exp} E_{cr}}\right)\right]\right)^{15/13}$$

Once a stable crust forms, another cooling mechanism that can contribute to a debris stabilization is melt eruptions. The following correlation by Ricou and Spalding[4] provides a conservative estimate of the actual entrainment coefficient for the various tests in which eruptions were observed:

$$j_m = K_e j_g, \quad \text{where} \quad K_e = E\left(\frac{\rho_g}{\rho_m}\right)^{1/2}$$

2.3 Simulation Results

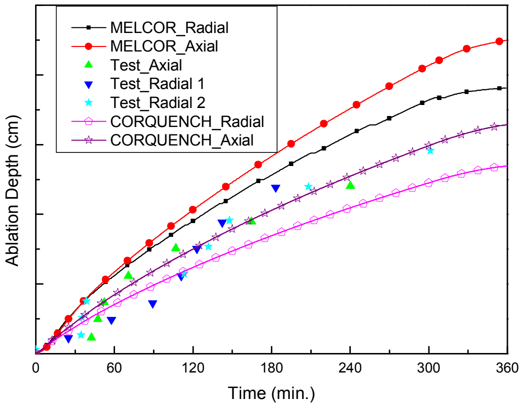

Fig. 2 Comparison of Ablation Depth

Figure 2 shows the ablation depths in the radial and axial directions. The CORQUENCH calculations generally predict the measured values better than the MELCOR calculation. When compared with the MELCOR calculations, both the ablation depths are lower than the MELCOR calculations.

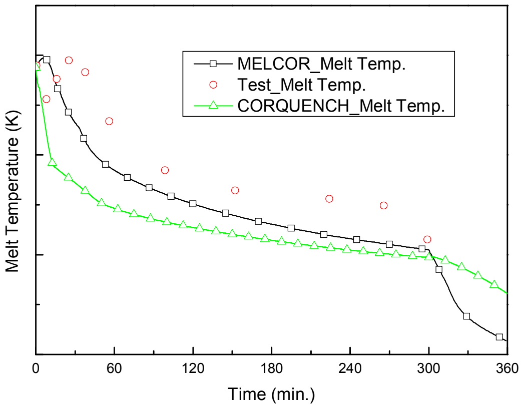

Fig. 3 Comparison of Melt Temperature

Figure 3 shows the melt temperature with time. The COEQUENCH calculations underestimate the measured melt temperatures. When compared with the MELCOR calculations, the melt temperatures are lower than the MELCOR calculations before a water injection, but higher than the MELCOR calculations after a water injection. It is shown that the melt temperature sharply decreases because of a very large heat transfer to the upper coolant at a water injection.

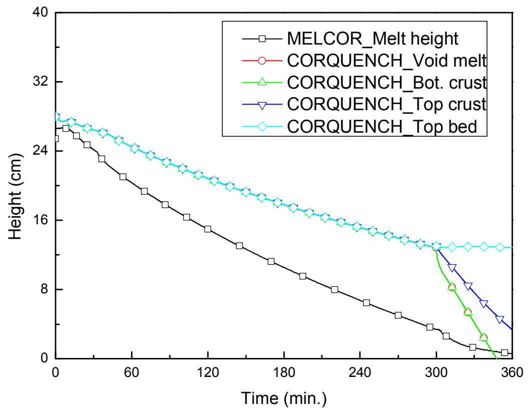

Fig. 4 Comparison of Melt Height

Figure 5 shows the comparison of the melt height. In the CORQUENCH calculations, the debris beds are formed at the upper crust after a water injection starts unlike the MELCOR calculations because the Ricou & Spalding model is incorporated in the code. The melt heights are generally lower than the MELCOR calculations.

3. Conclusion

Transient simulations of the CCI test were performed by using CORQUENCH Version 3. The calculations were compared with the test results and previous MELCOR calculations. Both the axial and radial ablation depths predict the measured values better than the MELCOR results. The melt temperatures generally underestimate the measured ones. They are lower than the MELCOR calculations before a water injection, but higher than the MELCOR calculations after a water injection. The melt heights are generally lower than the MELCOR calculations.

REFERENCES

[1] M. T. Farmer, S. Lomperski, D. J. Kilsdonk, and R. W. Aeschlimann, “2-D Core Concrete Interaction (CCI) Tests: CCI-2 Test Data Report-Thermalhydraulic Results”, *OECD/MCCI-2004-TR05, Rev. 0*, Oct. (2004).

[2] M. T. Farmer, “CORQUENCH 3.0 User’s Guide”, *OECD/MCCI-2007-TR01*, Feb. (2007).

[3] H. Y. Kim, J. H. Song, and H. D. Kim, “Calculations of Core Concrete Interaction Using MELCOR 1.8.5”, *Proc. KNS Spring*, Jeju, May (2005).

[4] F. B. Ricou and D. B. Spalding, "Measurements of Entrainment of Axisymmetrical Turbulent Jets," *J. Fluid Mechanics, Vol. 11*, pp. 21-32, (1961).