Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

A Simulation of the Coolant Mixing Using the Coupled MARS-CUPID

Ik Kyu Park*, Jae Ryong Lee, Seung-Wook Lee, Han Young Yoon
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea, 305-353
**Corresponding author: gosu@keaeri.re.kr*

1. Introduction

This paper presents the simulation results of ROCOM TEST 1.1[1] by using the coupled MARS-CUPID code[2]. ROCOM TEST 1.1 was conducted for re-criticality aspect in the frame of the OECD PKL 2 Project the test G3.1 dedicated to the investigation of a fast cool down transient. The transient was initiated by a main steam line break. To investigate in more detail the thermal hydraulic behavior inside the reactor pressure vessel (RPV) complementary tests on the coolant mixing were conducted at the ROCOM (Rossendorf Coolant Mixing) test facility.

2. Mathematical Model

For convenience, let us define Ci and Mi as the index numbers of i-th interfacing cells in the CUPID and MARS regions, respectively. In the MARS code, cell Ci is treated as a “CUPID boundary volume (cupvol)”, whose scalar variables are updated every time-step by CUPID. In the CUPID code, cell Mi is regarded as a sink that is implicitly coupled. The pressure correction matrices, which are set up in each module, are coupled via the momentum modeling at the interfaces and solved simultaneously.

The momentum balance at the interface junction from cell Ci to Mi is modeled by the MARS code, where the old time-step variables of cell Ci are transferred from CUPID. Then, the phasic volume flow at the i-th interface junction $\psi_{k,i}^{n+1}$ is given by

$$\psi_{k,i}^{n+1} = \alpha_{k,i} + \beta_{k,i}\left(\delta P_{Ci} - \delta P_{Mi}\right). \qquad (1)$$

Effects of the connections should be taken into account for the conservation of momentum in the CUPID region. Because of the MARS-CUPID connections, the pressure correction equation of MARS involves additional unknown terms that include the unknown velocities at the interfaces:

$$\underline{\underline{A}}_M \delta P_M = \underline{b}\alpha_{k,i} + \sum_{i=1}^{NC}\left(\underline{\gamma}_{l,i}\Psi_{l,i}^{n+1} + \underline{\gamma}_{g,i}\Psi_{g,i}^{n+1}\right) \qquad (2)$$

where $\underline{\gamma}_l$ and $\underline{\gamma}_g$ are coefficient vectors. Likewise, the pressure correction equation of CUPID is also changed due to the connection:

$$\underline{\underline{A}}_C \delta P_C = \underline{b}_C + \sum_{i=1}^{NC}\left(\underline{\kappa}_{l,i}\Psi_{l,i}^{n+1} + \underline{\kappa}_{g,i}\Psi_{g,i}^{n+1}\right) \qquad (3)$$

where $\underline{\kappa}_l$ and $\underline{\kappa}_g$ are coefficient vectors. Inserting Eq. (1) into Eqs. (2) and (3), a coupled pressure correction equation for the whole system can be established. The coupled equation is solved by using a domain decomposition method. After solving it, the remaining numerical sequences are completed in each code.

3. Verification and Application

In order to validate the coupled code, MARS-CUPID, ROCOM test 1.1 was simulated. The ROCOM RPV model were modeled with 37,068 3-D hexagonal finite volumes (Figure 1), and the pipes, pumps, and valves of the four loops were modeled with 80 1-D volumes (Figure 2). The special 8 volumes, last eight large volumes of each legs of Figure 2 and central eight volumes of Figure 2, connect a set of 3-D finite volumes and a set of 1-D volumes by the coupled schemes introduced in the above chapter. A right-low part loop of Figure 2 has a time-dependent injection and section volumes in order to simulate a overcooled loop, in which the flow rate is four times as much as those in other three loops.

The mixing drum in the lower head and the pipes in the core were simulated by the pressure drop and the porosity. Thus, both open media and porous media approaches are adapted in the CUPID code to optimize the physical phenomena and the calculation speed. Initially, the system was in stationary flow state at about 40 bar and 500 K, and the calculation started by operating three pumps. After that, the cold water of about 400 K was injected with a four times flow rate during 0.8 normalized time (NT), and the pump was stopped. This calculation was done by adopting zero equation model with 15 times mixing length of the diameter of the legs.

The calculated temperature distribution at 0.4 NT after the start of the cold injection in the ROCOM RPV model is presented in the Figure 3. The figure shows that the cold water injected into one cold leg flows via downcomer to the core and mixes with hot water. The calculated average temperatures over the core inlet, inner downcomer, and outer downcomer are compared to the measured ones in Figure 4, respectively. The both downcomer temperatures drop slowly first at 0.1 NT after the start of the cold injection, and the core inlet temperature drops relatively rapidly considering the dropping rate of both downcomer temperatures. The both downcomer temperatures rapidly recover from 0.8 NT when the cold water injection stops, but the recovery rate of the core inlet temperature is relatively low.

These overall trends of the calculated temperatures agree with those of the measured ones, though the calculated temperatures are higher than measured ones. The coarse mesh at the downcomer as a radially 6 grid induced well mixing behaviors at inner and outer downcomer walls and it resulted in the overestimation of the temperatures. Thus, the calculated minimum temperatures in the downcomer are higher than measured one in Figure 5. In this figure, the difference between the calculated and measured minimum temperatures in core inlet is much smaller than the difference in the downcomer due to the mixing in the lower head mainly becaue the mesh effect was not much in the core.

The calculated distributions in the core inlet are compared to measured one in the Figure 6. These are averaged values from 0.7 to 0.8 NT after the start of the cold injection. The two profiles are in a reasonable agreement each other.

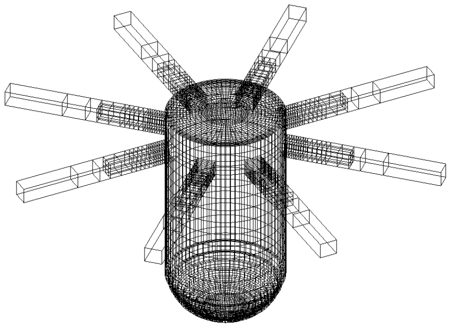


Fig. 1 37,068 3-D hexahedral volumes for ROCOM RPV

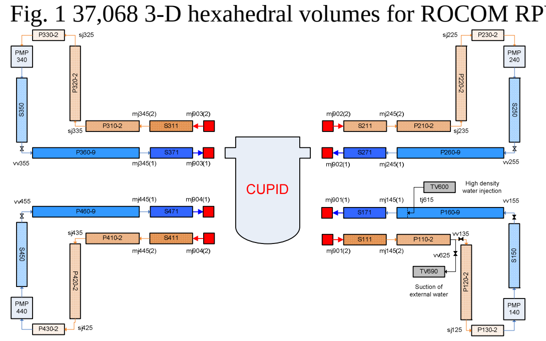


Fig. 2 A System mesh of 1-D volumes for ROCOM 4 loops

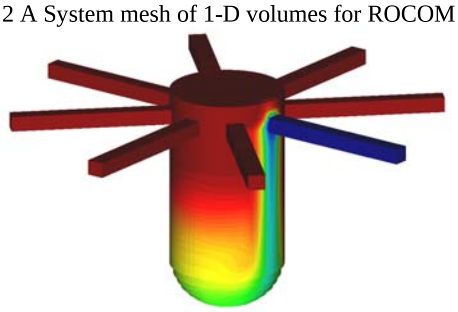


Fig. 3 Calculated coolant temperature distribution at 50s after dense water injection in the ROCOM RPV.

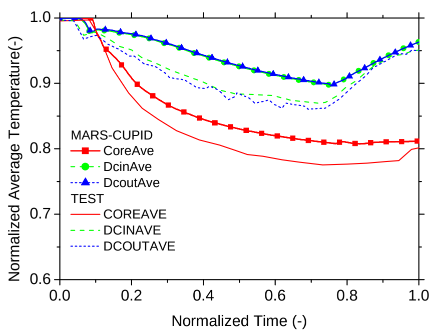


Fig. 4 Comparisons of average temperature at core inlet, inner downcomer, and outer downcomer

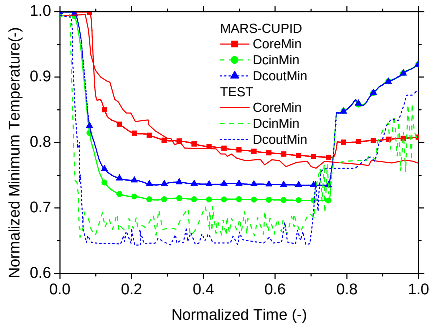
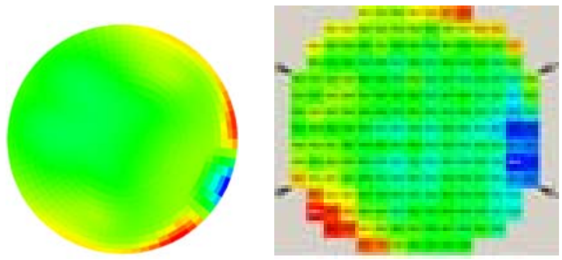


Fig. 5 Comparisons of minimum temperature at core inlet, inner downcomer, and outer downcomer



(a) MARS-CUPID (b) TEST

Fig. 6 Comparisons of coolant temperature distribution at the core exit

4. Summary and Conclusions

This paper introduced a simulation of the coolant mixing using the coupled MARS-CUPID code. The calculation results showed that the coupled scheme was physically acceptable and the multi-scale calculation was very practical and promising in the engeering aspects considering the calculation time and the accuaracy.

ACKNOWLEDGEMENTS

This work was supported by the Nuclear Research and Development Program of National Research Foundation of Korea (NRF) with a grant funded by the MEST (Ministry of Education, Science and Technology) of the Korean government.

REFERENCES

[1] S. Kliem, R. Franz, Quick-look report of the ROCOM Tests 1.1 and 1.2 conducted within the OECD PKL2 Project, Institutsbericht FZD\FWS\2010\07.

[2] J. J. Jeong, H. Y. Yoon, I. K. Park, and H. K. Cho, "The CUPID code Development and Assessment Strategy," Nuclear Engineering and Technology, 42(6), pp.636–655 2010.