Assessment of MARS for Direct Contact Condensation in the Core Make-up Tank

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1. Introduction

In order to improve safety features under loss of coolant accident (LOCA) conditions, in many advanced light water reactors, gravity driven passive safety injection systems (PSISs) replace active pump driven emergency core cooling systems. Among various PSISs, the core make-up tank (CMT) with the pressure balancing line (PBL) and the coolant injection line (IL) represents an effective means of providing core cooling. Because the fluid is always sensing the reactor coolant system (RCS) through the PBL connecting the inlet of the CMT to the pressurizer in the case of CP1300 or to the cold legs in the case of AP600/1000, the CMT can provide cold water at any RCS pressure by gravity force [1]. However, after the initiation of LOCAs, if the injection (or isolation) valve is opened, and the steam from the RCS is jetting into the highly subcooled liquid in the CMT and the enhanced interfacial area results in rapid condensation, which in turn, causes a rapid pressure drop in the CMT. As a result, the CMT pressure becomes less than the RCS pressure, and the injection of the CMT can be delayed until the CMT pressure builds up due to greatly reduced condensation in the CMT by the thermal stratification. In order to identify the parameters having significant effects on the gravity-driven injection and the major condensation modes, Lee & No (1998) conducted the separated effect tests of CMT with a small-scale facility [2].

MARS has been developed as a multi-dimensional thermal-hydraulic (TH) system analysis code for the realistic simulation of two-phase TH transients for pressurized water reactor plants. As the backbones for the MARS code, the RELAP5/MOD3.2 and the COBRA-TF codes were adopted [3]. Recently, Chun et al. (2013) evaluated performance of the SMART passive safety system for SBLOCA using MARS code [4]. However, it is not clarified that MARS can simulate properly the direct contact condensation in the CMT. Thus, in this study, we assess the analysis capability of the MARS code for the behaviors of the CMT.

2. MARS code modelling

We perform MARS simulations of KAIST-CMT separated effect tests which were conducted by Lee & No (1998). As shown in Fig. 1, the test facility consists of the test section simulating the CMT, steam generator (SG) simulating the pressurizer or the RCS, and the measurement system. The CMT is a tank with 85cm height and 65cm diameter with 1/7 (height) and 1/35 (area) scaling ratios relative to the CMT of the AP600 [2].

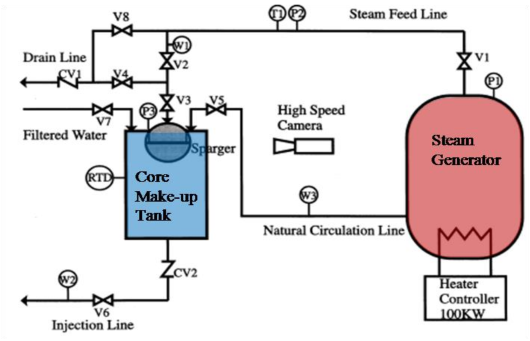

Fig. 1 Schematic diagram of test facility[2]

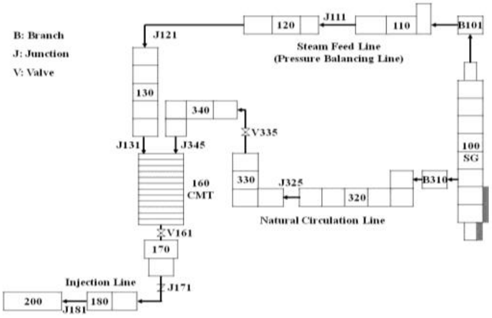

Fig. 2 Schematic diagram of MARS nodalization.

The MARS nodalization is represented in Fig. 2. The nodalization model is consisted of 54 volumes connected by 53 junctions and 3 heat structures for the electric heater. The SG (100), the PBL (110, 120, 130), the CMT (160), the IL (170 180), the natural circulation line (320, 330, 340) is modeled by pipe components. The injection valve (V161) and natural circulation valve (V335) are modeled by servo valve components which are opened at 10s within 1s. A check valve (J171) with a very large backward form loss coefficient is installed in the IL to prevent a back flow from a water reservoir because of large pressure drop in the CMT due to rapid condensation. After opening the injection valve, the water drains to water reservoir (200), whereas it drains to atmosphere in the experiment.

3. Code Calculation Results

3.1 Analysis of Node Sensitivity and Basic Phenomena

A nodalization sensitivity study was performed to investigate the effects of the number of nodes (N) in the CMT for 2, 4, 8, 12, and 16 nodes for the case of the

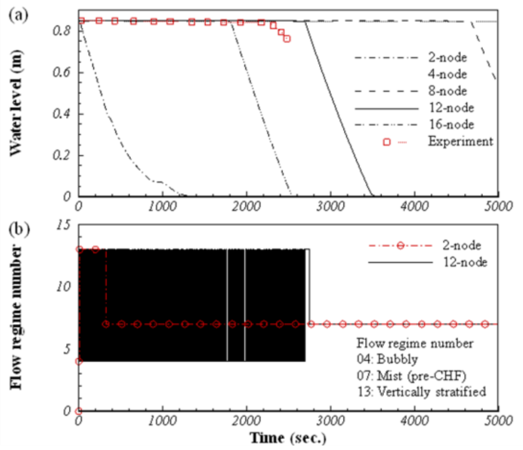

Fig. 3 The effect of nodalization of MARS in the simulation of the CSLI31: (a) CMT water level; (b) CMT flow regime at 1st node

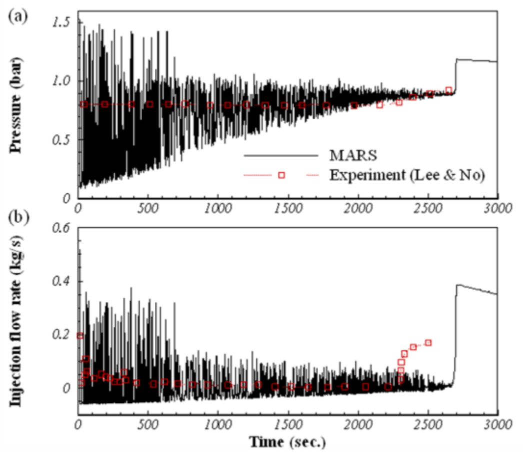

Fig. 4 The simulation of the CSLI31: (a) CMT pressure; (b) Injection flow rate

CSLI31 (P_{SG} = 1.43 *bar*, T_{CMT} = 31℃). The results from the nodalization sensitivity study are compared with KAIST experimental data in Fig. 3. The injection behaviors of the CMT significantly depend on the *N* and it can be categorized by two regions; $N < 4$ and ≥ 4. At $N < 4$, flow regime of the 1st node in the CMT goes to the vertically stratified flow and the test section begins to inject as soon as the injection valve is opened, whereas it is oscillated in between the vertically stratified flow and the bubbly flow and the initiation of injection is delayed until flow regime is fixed to the vertically stratified flow at $N \geq 4$. In the comparison of the initiation time of injection, the results of the 12-node model well agree with the experimental data. Thus, the 12-node model is set to a base case.

For base case calculations, the CSL31 are simulated using MARS to determine if it can simulate the physical phenomena occurring in the CMT. As show in Fig. 4, MARS can simulate general behavior of the CMT pressure and the injection flow rate properly. In detail, these physical properties calculated by MARS highly oscillates, because the oscillation of flow regime in the CMT leads to frequent changes of interfacial heat transfer coefficient between the steam and the subcooled water in the top of the CMT.

3.2 Effects of water subcooling, pressure, and natural circulation flow

The effects of the water subcooling of the CMT (T_{CMT} = 31, 61, and 91℃), steam pressure (P_{SG} = 1.43 and 2.0 *bar*), and the natural circulation flow on the injection behavior of the CMT are investigated through the MARS simulations. In the case of T_{CMT} = 31℃ and 61℃, the initiation time of injection are 2700 and 1050 s, respectively. In the case of T_{CMT} = 91℃, the CMT begins to drain as soon as the injection valve is opened at 10 s. The higher the steam pressure is, the earlier the injection time of the CMT initiates because large steam flux increases the temperature of the upper hot water layer rapidly. Finally, the results show that the natural circulation flow of the hot water from the SG to the top of the CMT accelerates the injection of the test section.

4. Conclusions

This study aimed at assessing the analysis capability of a reactor system analysis code, MARS for the behaviors of the CMT. The sensitivity study on the nodalization of the CMT was conducted, and the MARS calculations were compared with KAIST experimental data. The number of the CMT nodes was fixed to 12 through this node sensitivity study. The sensitivity studies on various parameters, such as water subcooling of the CMT, steam pressure, and natural circulation flow were done. MARS calculations were reasonable in the injection time and the effects of several parameters on the CMT behaviors even though the mesh-dependency should be properly treated for reactor applications.

Acknowledgments

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