Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2026

Refilling Experiments in an MSR Drain System Mock-up for the Validation of System Codes

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Keywords : MSR, molten salt reactor, fuel salt drain system, two phase, MARS, GAMMA+

1. Introduction

In molten salt reactors (MSRs), the fuel salt drain system is primarily provided to transfer liquid fuel from the core to subcritical storage tanks during planned shutdowns and off-normal conditions. Once the core has been drained, however, the same plant cannot be brought back to power unless the fuel salt is reintroduced into the vessel through a controlled refilling process. MSRs employ liquid fuel and will undergo repeated discharge–refill operations over their lifetime for maintenance, abnormal events, or fuel processing interfaces.

To restart the reactor with the intended core inventory, the refilling operation must deliver neither less nor more than the target amount of fuel. This requires a well-defined refilling logic that accounts for the detailed dynamics of liquid-level rise, hydraulics through the piping, and the behavior of trapped gas volumes. As a preliminary step toward establishing such a logic, the present study performs water refilling tests in a scaled MSR drain system mock-up, injecting water from the lower drain tank into the upper tank under controlled pressurization.

In a simple piping layout, such tests would offer limited value, since one-dimensional analysis would be expected to capture the behavior with little ambiguity. In the K-MSR drain system, however, a siphon pot dedicated to freeze-valve operation is located along the flow path, and this feature complicates both drainage and refilling by introducing localized gas holdup and nontrivial interface motion. To clarify these effects and to evaluate the suitability of existing tools, the refilling experiments are compared with simulations using the thermal-hydraulic system codes MARS-KS and GAMMA+, focusing on their ability to reproduce the observed level evolution and void distribution in the siphon-pot region.

2. Experimental Setup

The refilling experiments were conducted using an MSR drain-system mock-up constructed to approximately one-quarter of the KAERI's MARINA drain system size. Since the reference design is still under development, the facility does not represent a strict geometric or dynamic scale, but it was built to examine the fundamental hydraulic behavior expected during the drain and refill processes. A photograph of the apparatus is shown in Fig. 1, and the major components with their dimensions are summarized in Table I.

Fig. 1. MARINA drain system mock-up

Table I: Components and dimensions

Component	Diameter(m)	Length (m)
FSL Tank	0.48	1.0
DL-1	0.032	0.045
FV-1	0.032	0.175
Bend-1	0.032	0.145
DL-2	0.032	1.25
Bend-2	0.032	0.145
DL-3	0.032	0.28
Bend-3	0.032	0.145
FV-2	0.032	0.175
Bend-4	0.032	0.145
Siphon pot	0.032	0.04
	0.075	0.125
	0.032	0.04
Bend-5	0.032	0.145
DL-4	0.032	0.3
Bend-6	0.032	0.145
DL-5	0.032	1.145
Drain Tank	0.7	0.72

The loop consists of a Drain tank at the bottom, a pressurization line connected to an external air supply, a vertical riser, several bends, a siphon pot, and an FSL (Fuel Salt Liquid) tank located at the top. All piping sections were fabricated from transparent acrylic to allow visualization of the water–air interface and the motion of trapped gas inside the siphon-pot region.

To set the refilling condition, the target water level in the FSL tank was 80 cm, and this level was achieved by pressurizing the Drain tank to a gauge pressure of 0.24 bar while maintaining an initial water level of 61 cm in the Drain tank. A small residual water layer of about 1.5 cm was present in the FSL tank at the beginning of the test, as complete drainage of the upper tank is not possible due to the loop geometry.

The FSL tank level was measured using a differential-pressure gauge, while a non-contact level sensor was used to monitor the Drain tank level. These instruments provided continuous tracking of the liquid-level evolution throughout the refilling process.

3. Simulation Methods

The refilling tests were simulated using MARS-KS 2.0 and GAMMA+ (version 260101). The nodes were constructed to match the geometry of the mock-up, including the Drain tank, riser, bends, siphon pot, and FSL tank. The pressure boundary at the Drain tank was set to the measured gauge pressure used in the experiment. The loop was discretized into one-dimensional control volumes as shown in Fig. 2, and the same nodalization and hydraulic loss coefficients were applied to both codes. The initial water levels in the Drain tank and FSL tank were set identical to the experimental conditions. No additional model adjustments were introduced.

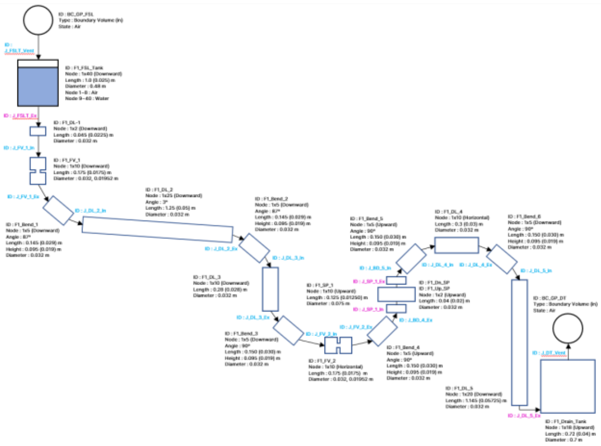

Fig. 2. Nodalization for both MARS and GAMMA+

4. Results and Discussion

Fig. 3 shows the comparison of the measured FSL tank water level with the MARS-KS and GAMMA+ results. In the early stage of the transient, MARS-KS under-predicts the level rise and shows a slower increase than the experiment, resulting in a noticeable deviation from the measured curve. GAMMA+, on the other hand, follows the experimental trend more closely, although its predicted level is slightly higher than the experiment during this period. As refilling progresses, GAMMA+ reaches the target level earlier than the experiment and exhibits a small overshoot, after which the level continues to oscillate instead of settling. MARS-KS approaches the final level more gradually but remains below the experimental value throughout the late stage of the transient.

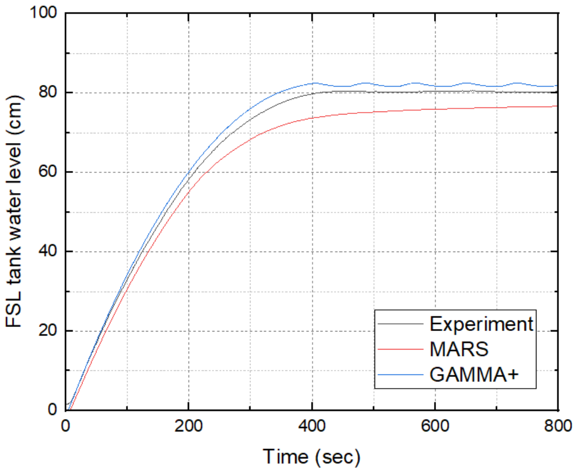

Fig. 3. FSL tank water level through the time

Although the two codes were modeled with the identical nodalization and boundary conditions, their final stabilized water levels differ. In the MARS-KS simulation, when the FSL tank level approaches its final height, bend-5 becomes completely voided. As a result, the hydrostatic head transmitted from the Drain tank to the FSL tank is reduced by the vertical length of this gas-filled region, producing a lower final water level than the experiment. The GAMMA+ result also deviates slightly from the experiment, which is attributed to differences in the void-fraction distribution inside the piping during the late stage of refilling.

Fig. 4 presents the predicted residual water distribution in the piping at the end of the transient for each code. Fig. 5 shows the corresponding experimental observation. In MARS-KS, the complete voiding at bend-5 leads to a smaller amount of liquid retained in the upper part of the loop. GAMMA+ predicts partial liquid holdup in several sections, but the locations and volumes differ from the experimental pattern.

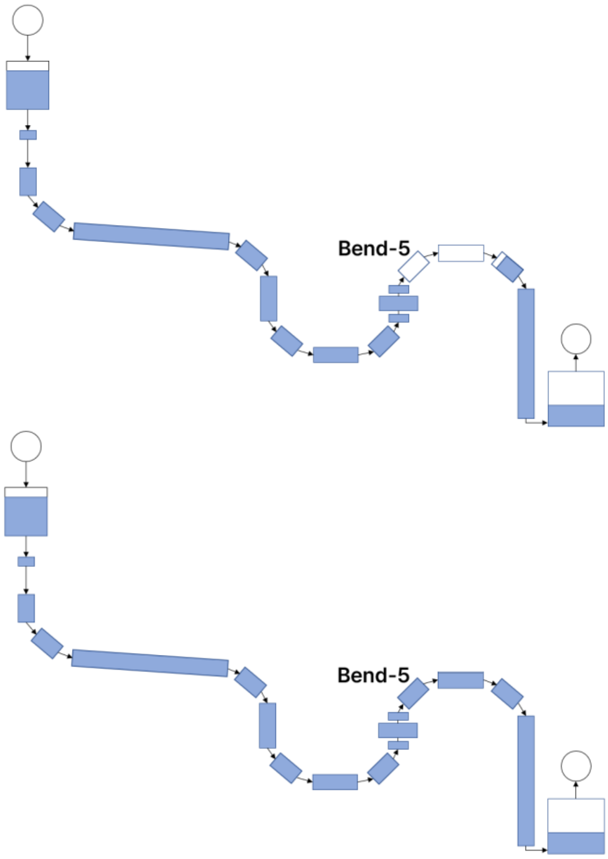

Fig. 4. Schematic distribution of residual water at the end of refilling (▲MARS-KS, ▼: GAMMA+)

Fig. 5. Observed residual water distribution in the mock-up experiment at the end of refilling.

Also, during the experiment, a stable air pocket was observed at the upper part of the siphon pot throughout most of the transient, as shown in Fig. 5. This pocket collapsed only near the end of the refilling process. However, neither MARS-KS nor GAMMA+ reproduced this behavior. In both calculations, the siphon-pot region becomes filled with liquid immediately, and no long-duration gas pocket is maintained. The inability to sustain this gas region appears to be related to the one-dimensional interfacial models used in both codes.

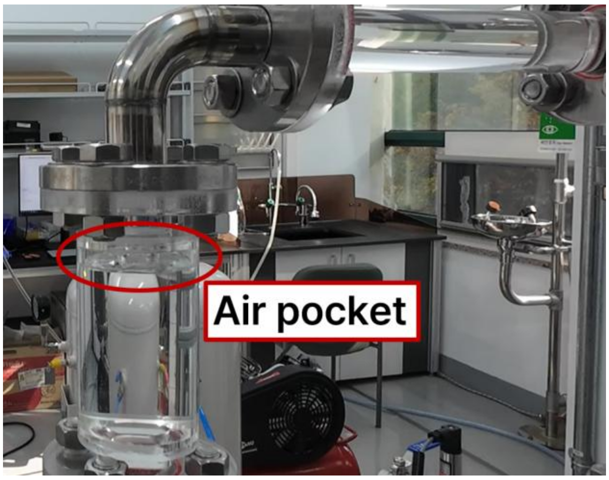

Fig. 6. Observed air pocket in the mock-up experiment during the refilling.

5. Conclusions

Refilling tests were performed in the molten salt reactor MARINA drain-system mock-up, and the results were compared with predictions from MARS-KS and GAMMA+. Both codes reproduced the overall level-rise trend, but clear differences appeared in the late stage. MARS-KS under-predicted the final level because a fully voided region was formed near Bend-5, reducing the effective hydrostatic head, while GAMMA+ maintained liquid holdup in this region and produced a higher final level. The long-duration air pocket observed experimentally in the siphon pot was not captured by either code.

The origin of these discrepancies will be analyzed in more detail, and the outcome will be used to establish a more reliable approach for predicting the hydraulic behavior during pressurized refilling. The improved understanding will be reflected in the development of refilling logic and in the future design and evaluation of the MARINA drain system.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF), grant funded by the Korea government (MSIT) (RS-2023-00259713).

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