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GAMMA-FR and MELCOR code comparison with respect to density driven flow

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1. Introduction

During the 12th Working Meeting of the WG-TSDU(Working Group - TBS Safety Demonstration Update), Jacobs and F4E presented their experiences with the fusion-adapted versions of the MELCOR codes. In that meeting, the results of the same density-driven flow test performed using MELCOR versions 1.8.2 and 1.8.6 were presented, with MELCOR 1.8.2 reported to be inconsistent. To further investigate these findings, the Korea Domestic Agency (KODA) performed a cross-comparison by using GAMMA-FR code. This paper presents a detailed comparison between the GAMMA-FR and MELCOR codes, with a particular emphasis on their performance in simulating density-driven flow. The results of this comparison aim to provide deeper insights into the capabilities and limitations of MELCOR code, contributing to the ongoing efforts to enhance safety analysis tools for fusion reactor design.

2. Safety Analysis Code

For analysis, MELCOR 1.8.2, MELCOR 1.8.6, and GAMMA-FR (General Analyzer for Multi-component and Multi-dimensional Transient Application – Fusion Reactor) were used. Among these, the MELCOR code is widely used in the field of nuclear fusion. The GAMMA-FR code is a system code has been developed in KAERI (Korea Atomic Anergy Research Institute) [1] to predict thermo-hydraulic and chemical reaction phenomena expected to occur during thermo-fluid transients.

4. Parameters and nodalization

The model used in this study consists of two distinct volumes, designated as Volume A and Volume B, which are connected by two junctions. Volume A represents a high-density region filled with air. The air in this volume is characterized by a pressure of 0.1 MPa, a temperature of 25.0 ℃, and a density of 1.168926 kg/m³. This volume has a cross-sectional area of 0.1 m² and extends over a total length of 3 meters. Volume B represents a low-density region filled with helium. The helium in this volume is also maintained at a pressure of 0.1 MPa and a temperature of 25.0 ℃, but with a significantly lower density of 0.161483 kg/m³. Volume B also has a cross-sectional area of 0.1 m² and a length of 3 meters.

These two volumes are interconnected by two junctions, each with an area of 0.01 m². The junctions facilitate the flow between the high-density air in Volume A and the low-density helium in Volume B, allowing for the analysis of density-driven flow across the boundary between these two distinct fluid regions.

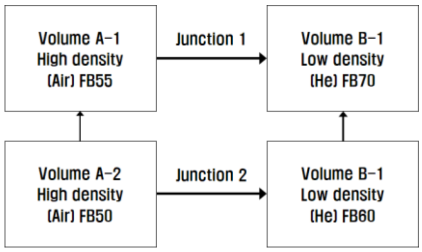

Fig. 1. Nodalization of the analysis

5. Results

Figure 1 shows the calculation results using MELCOR 1.8.2, illustrating the mass flow rates calculated at the upper and lower junctions. The red line represents the lower junction and indicates the mass flow rate of air from Volume A moving towards Volume B due to the density difference. The black line is the mass flow rate of helium (lower density) in the opposite direction through the upper junction. It is depicted as a negative value.

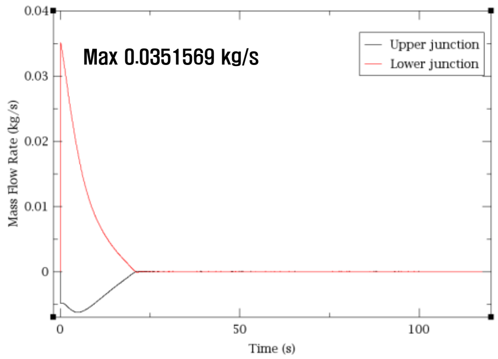

Fig. 2. Mass flow rate of each junction (MELCOR 1.8.2)

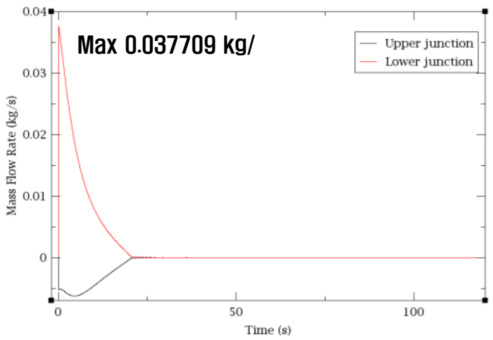

Fig. 3. Mass flow rate of each junction (MELCOR 1.8.6)

MELCOR 1.8.6 shows 7% more maximum mass flow rate than that of MELCOR 1.8.2. (Figure 3). GAMMA-FR and MELCOR 1.8.6 are reasonably agreeable each other (~1% deviation). In the figure 4, GAMMA-FR and MELCOR 1.8.6 are almost identical in mass flow trend in each junction. This simple test model is a closed loop, therefore, density driven oscillation can take place until it stabilizes. GAMMA-FR can capture this physical phenomenon.

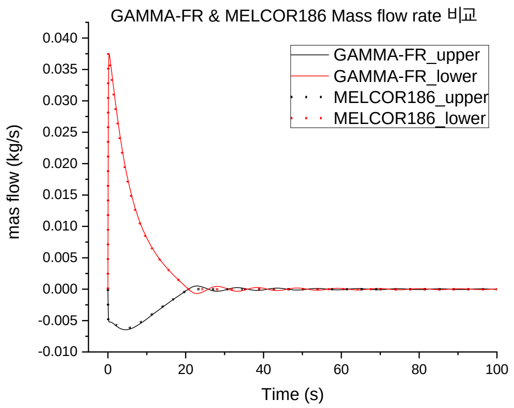

Fig. 4. Mass flow rate comparison of each code

Figures 5 and 6 display the time-dependent changes in density for each individual volume in the nodalization. Figure 5 focuses on a relatively short duration, showing changes up to 150 seconds. It can be observed that the dashed line, representing the MELCOR calculation results, closely matches the solid line, which represents the GAMMA-FR calculation results. Figure 6 shows the results of the calculation extended to 6000 seconds, continuing from the analysis in Figure 5. While the short-term results showed similar trend between the two codes, the long-term calculations reveal differences. This test simply aimed to model the physical mixing of air and helium due to their density difference. The GAMMA-FR code includes a molecular diffusion model, allowing it to simulate the process where the two gases mix and converge to a single density over time. In contrast, the MELCOR code behaves as if air and helium remain stratified like oil and water, with air remaining in the lower volume and helium in the upper volume, even in long-term calculations. In terms of gas mixture density, MELCOR has limitation for the long-term calculation. Therefore, two codes show similar results in the short-term estimation, however, MELCOR can mislead equilibrium mixture density of each volume in the final state.

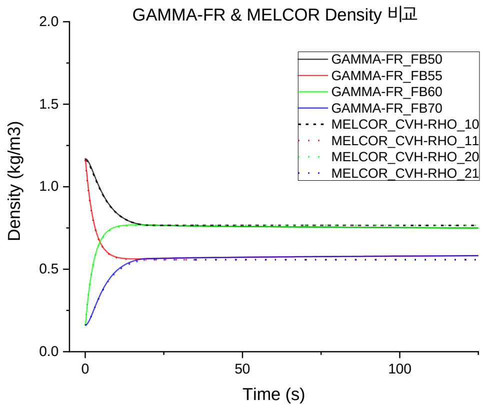

Fig. 5. Density comparison of each code (short term)

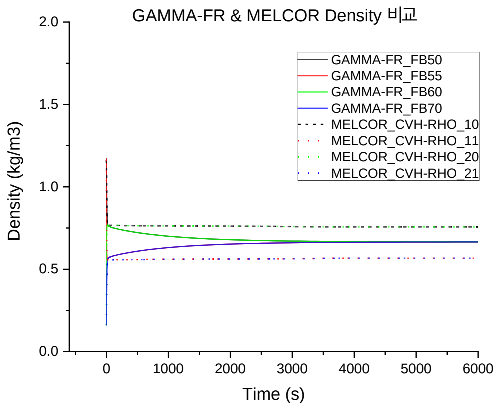

Fig. 6. Density comparison of each code (long term)

5. Conclusion

A successful comparative analysis of density-driven flow was conducted using the GAMMA-FR and MELCOR codes. Overall, both codes effectively modeled the phenomenon; however, the long-term analysis revealed limitations in the MELCOR code. In accident analysis for nuclear fusion systems, where predicting the distribution of light gases like hydrogen is crucial, the two codes may produce different results. It is anticipated that MELCOR could overestimate hydrogen concentration in certain regions, diverging from real-world conditions.

REFERENCES

[1] H. S. Lim et al., GAMMA multidimensional multicomponent mixture analysis to predict air ingress phenomena in an HTGR, Nucl. Sci. Eng. 152 (2006)