

GAMMA+ Simulation of Sodium Experiments for Thermal Stratification in Upper Plenum of Sodium-Cooled Fast Reactors

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1. Introduction

The GAMMA+ code [1] was originally developed for thermo-fluid transients and system analysis of a high temperature gas-cooled reactor (HTGR). Currently, intensive researches to improve the capability of the GAMMA+ code for applications to a sodium-cooled fast reactor (SFR) are on-going in Korea Atomic Energy Research Institute (KAERI) [2,3]. As a part of these researches, the present work was carried out focusing on thermal stratification phenomenon in the upper plenum of the reactor vessel of an SFR.

It is known that thermal stratification may occur in the upper plenum of an SFR, in particular, after reactor shutdown. It could cause thermal stress and fatigue on various solid structures resulting in structural integrity issues. Therefore, lots of numerical and experimental researches on thermal stratification in the upper plenum of an SFR were performed in the past [4-6].

This paper presents GAMMA+ simulation of the sodium experiments performed by Ieda et al. [7] to study thermal stratification in the upper plenum of an SFR.

2. Sodium Experiments by Ieda et al.

Ieda et al. performed a series of sodium tests to investigate thermal stratification in the upper plenum of an SFR using the cylindrical steel vessel shown in Fig. 1. The facility was fabricated with 1/10 geometric scale for an existing SFR. The vessel had typical configuration of the upper plenum of an SFR including upper instrumentation structure (UIS) and inner barrel.

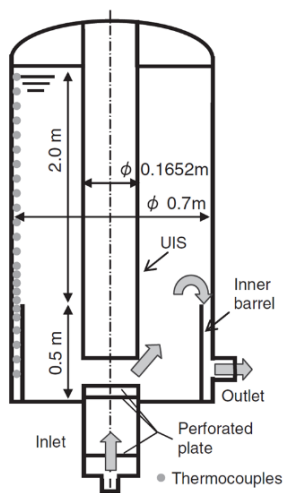


Fig. 1 Schematic of Ieda et al. thermal stratification experiment [8]

In the experiment, sodium flows into the upper plenum from the lower inlet pipe and flows out from the vessel to three outlet nozzles (located in three directions at 120 degree from each other) via an annular region between the inner barrel and the vessel. The free surface level of sodium was located about 2 m above the inner barrel, which is long enough that thick thermal stratification layer is formed and measured during the experiment. Among the series of tests performed by Ieda et al. only two cases (identified as Case A and Case B in this paper) are available to reproduce the boundary conditions and measured data in open literatures. Both experiments were carried out with changing the inlet temperature of sodium at a constant flow rate (5 liter per second). The measured inlet temperatures of sodium for Cases A and B are shown in Figs. 2 and 3, respectively. Many thermocouples were vertically placed (See Fig. 1.) and measured the temperature change of sodium with time during the experiment. Flow holes in the inner barrel were blocked in both cases.

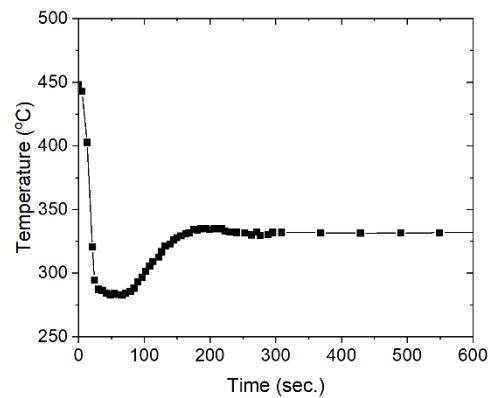


Fig. 2 Sodium inlet temperature for experiment Case A [8].

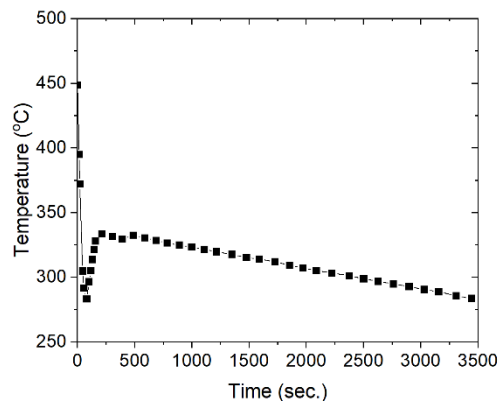


Fig. 3 Sodium inlet temperature for experiment Case B [7].

3. GAMMA+ Model

Fig. 4 shows the GAMMA+ nodalization to simulate the Ieda et al. experiment. 1-dimensional model was applied to the three outlet nozzles and 2-dimensional model was applied to the other regions based on the cylindrical coordinate. Free surface behavior in the sodium level was neglected. The inner barrel was modeled as heat structures allowing heat conduction across the thickness whereas UIS was neglected in the simulation. Experience from similar calculations confirmed that the effect of UIS is negligibly small.

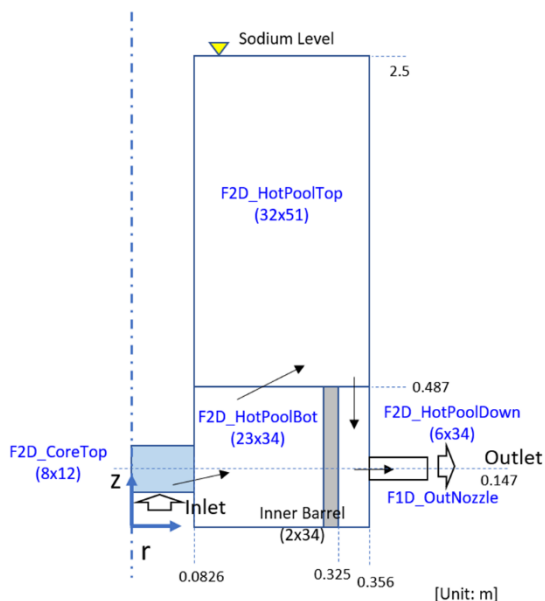


Fig. 4. GAMMA+ nodalization to simulate Ieda et al. experiment.

It should be noted here that fluid heat conduction is crucial in the thermal stratification and the related option in GAMMA+ has to be activated (which is a default option.). The adopted mesh size is finer than that of the existing calculation by Ieda et al. As a turbulence model, a mixing length model adopted in COMMIX-1C [9] was applied.

4. Results and Discussions

Fig. 5 shows the steady-state velocity vector calculated by GAMMA+. Flow recirculation at the upper and lower regions of the plenum can be clearly seen. It is obvious that the flow recirculation at the upper region of the plenum can largely affect the axial temperature distribution, i.e., thermal stratification. Therefore, accurate simulation of flow recirculation may be important in the prediction of thermal stratification. It means that multi-dimensional model is inevitable to simulate the experiment of Ieda et al. accurately.

Fig. 6 shows the results for the experiment Case A. It compares the axial temperature distribution obtained by GAMMA+ with the experimental data. The existing STAR-CD result by Ohno et al. [8] is added for additional comparison. The figure shows that the initial

temperature prediction is good but the difference between the GAMMA+ calculation and the measurement increases with time. It means that GAMMA+ predicts faster movement of thermal stratification than the measurement. The prediction by GAMMA+ is not as good as that of STAR-CD.

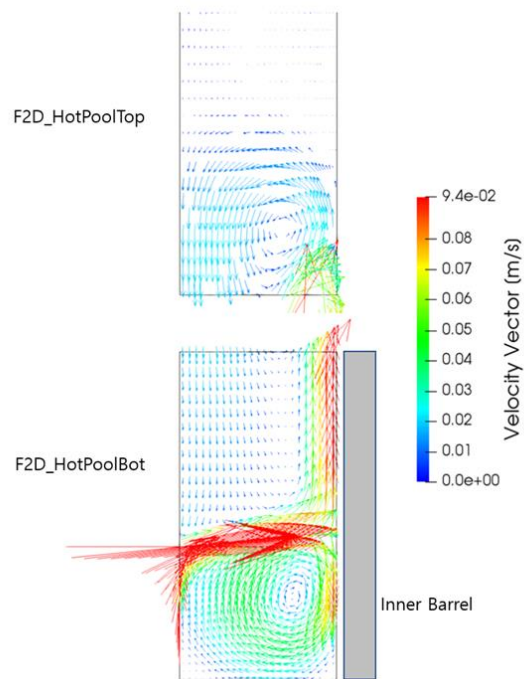


Fig. 5. Steady-state velocity vector obtained by GAMMA+.

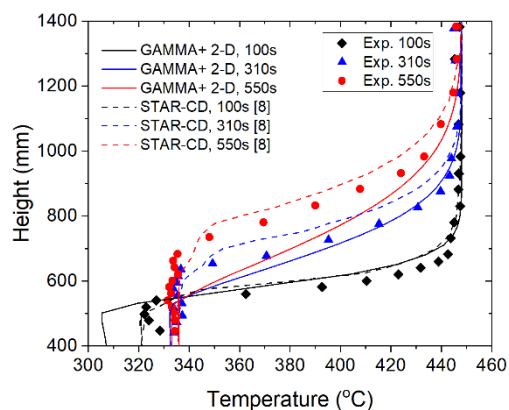


Fig. 6. Comparison of axial temperature distribution for experiment Case A.

The comparison for the experiment Case B is shown in Fig. 7. It also shows that GAMMA+ predicts faster movement of thermal stratification than the measurement. However, the accuracy of GAMMA+ is comparable to that of AQUA calculated by Ieda et al. (the same authors of the experiment). A modified k- ϵ model was used in the AQUA calculation. It means that the reason of the discrepancy between the numerical calculation and the measurement could be common. It seems that the discrepancy is mainly from the turbulence model adopted since the accuracy of the adopted turbulence

models by GAMMA+ and AQUA are not sufficiently validated against the Ieda et al. experiment conditions. It is clear that the flow regime at the plenum is not simple in the Ieda et al. experiment. The upper region of the plenum is laminar whereas the lower region is turbulent. Moreover, it contains large flow recirculation. It is expected, therefore, that more advanced turbulence could improve the numerical results of GAMMA+.

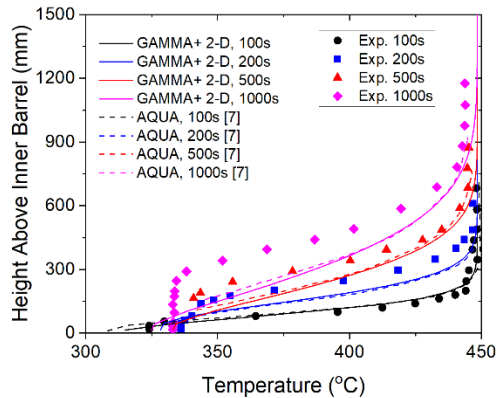


Fig. 7. Comparison of axial temperature distribution for experiment Case B.

5. Conclusions

In this paper, GAMMA+ simulation was performed for the Ieda et al. thermal stratification experiment. It is confirmed that accurate prediction of flow recirculation at the upper plenum is crucial to analyze the thermal stratification phenomenon. It is found that overall agreement between the GAMMA+ results and the measured data is good. But GAMMA+ predicts faster movement of thermal stratification than the measurement. The accuracy of GAMMA+ is found to be comparable to the existing numerical results performed by the same authors of the experiment. It is concluded that more advanced turbulence model should be considered to improve the GAMMA+ predictions. The existing study by Kim [10] indicates the possibility of implementation of advanced turbulence models to GAMMA+.

Acknowledgements

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