GAMMA+ Code Verification for Natural Circulation Phenomena in a MSR System

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing GAMMA+ code to analyze the reactor safety for non-LWR reactors[1]. Originally, the GAMMA+ code was developed to apply to a High Temperature Gas-cooled Reactor (HTGR). After numerous modification and improvement, the GAMMA+ has capability to simulate various reactor types including the Sodium-cooled Fast Reactor (SFR), Heat Pipe Reactor (HPR) and Molten Salt Reactor (MSR). But, the GAMMA+ code needs additional Verification and Validation (V&V) studies to apply to non-LWR system other than the HTGR system that the GAMMA+ code has multiple V&V studies.

The molten fuel mixture might circulate in the reactor core after shutdown by temperature gradient at outer surface. Therefore, the particular phenomena of MSR that fluid with a heat generation circulates should be investigated carefully. The results of the GAMMA+ code for natural circulation cavity with internal heat generation has been compared to those of the commercial CFD S/W CFX[2] on the present study.

2. Natural Circulation in Cavity

The simple and reliable verification approach is to simulate natural circulation in a square cavity in Fig. 1.

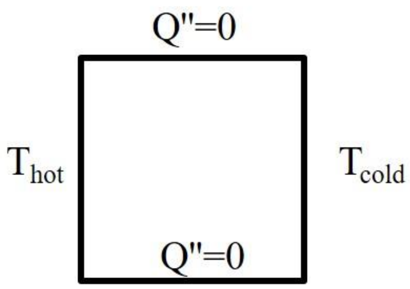


Fig. 1. Square cavity domain and boundary condition

The basic calculation was to compare the experiment result[3]. The Ra=1.89×10^5 condition was applied to the test. The results of the CFX and the GAMMA+ code were compared with the experimental data using air fluid in Fig. 2. The height, temperature difference between T_{hot} and T_{cold} were derived using air properties. Both the CFX and the GAMMA+ code are well matched with the measurement data.

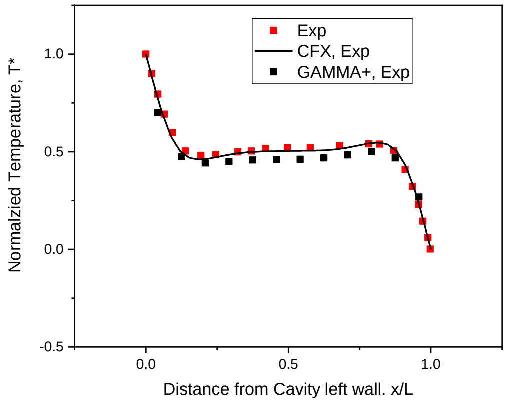


Fig. 2. Square cavity domain and boundary condition

Fig. 3 represent the cylindrical domain to compare the CFX code and the GAMMA+ code. The Ra=2.06, inner / outer side temperatures of 20°C and 40.3°C were selected as boundary condition. The top and bottom walls are treated as adiabatic condition. The radial and axial length is 0.1 m × 0.1 m. The angle between the front and the rear face is 30°. The working fluid is air. Total 37334 nodes were used to calculate the cylindrical domain. The calculated results of the GAMMA+ well agreed with the results of the CFX.

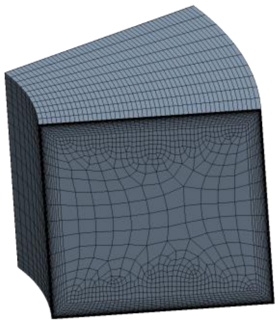


Fig. 3. Cylindrical domain

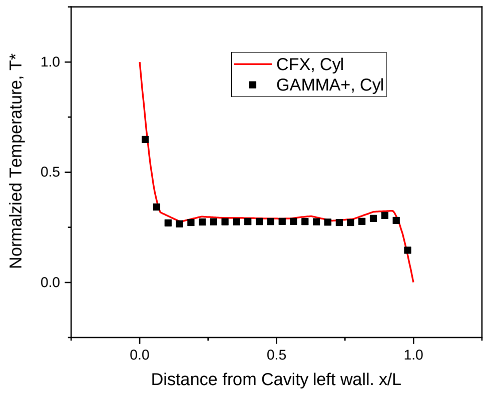


Fig. 4. Natural circulation in cylindrical domain

Next comparison calculations were conducted using fuel salt properties. There are many candidate fluids as the fuel salt. In this paper, NaCl-$MgCl_2$-UCl_3 was selected. The transport properties and density are following

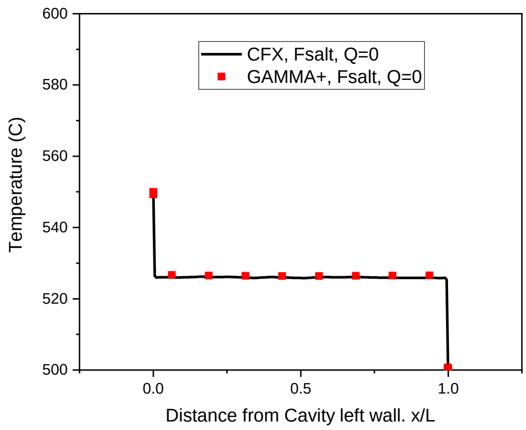
$$\mu = 3.49E - 4 \times \exp\left(\frac{1060.71}{T[K]}\right) [Pa\ s] \quad (1)$$

$$\kappa = 0.26 + 0.001 \times (T[K] - 273.15)[W/mK] \quad (2)$$

$$\rho = 3135.04 - 0.7554 \times (T[K] - 273.15)[kg/m^3] \quad (3)$$

The temperatures of the left and right walls are 550 / 500 ℃. The Rayleigh number was 7.96E11 at this condition. For the case of heat generation in the fluid, an order of decay heat in the reactor core was applied.

Figs. 5 and 6 show the calculated temperature and z-direction velocity profile for the case Q=0 and heat generation, respectively. The disturbance in the velocity profile in the CFX may come from the numerical instabilities by the CFX solver mechanism. Nevertheless, the GAMMA+ code well follow the results of the CFX.



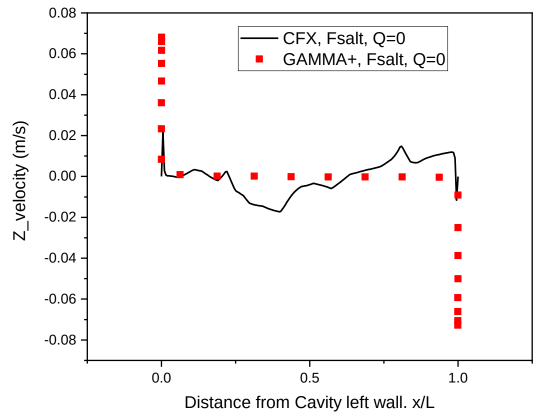


Fig. 5. Temperature and z-direction velocity with Q=0

The z-direction velocity calculated by the CFX showed upward value at the left region. But, the velocity calculated by the GAMMA+ was almost flat of zero. It is thought that the modeling method of the GAMMA+ might look to give the averaged value due to simple mesh and logics. The code will be analyzed more carefully in the future.

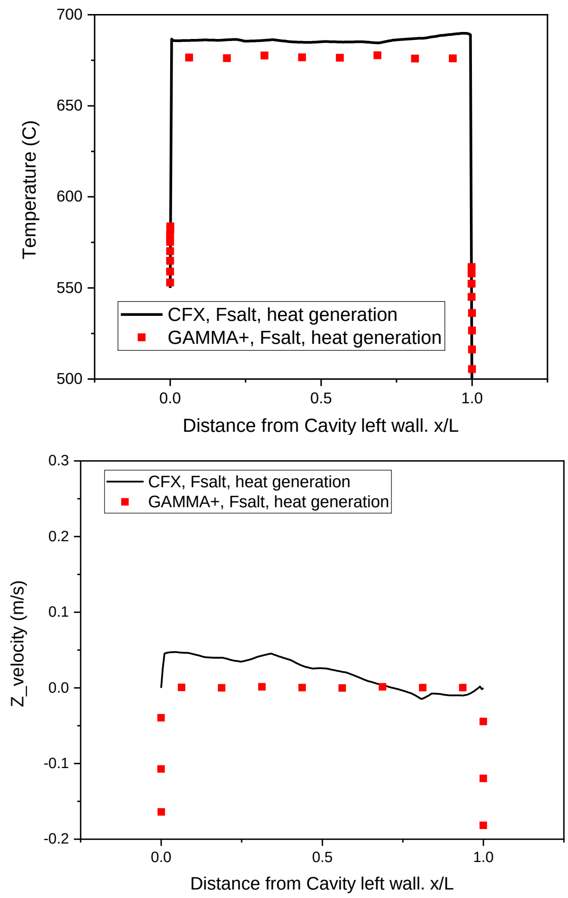


Fig. 6. Temperature and z-direction velocity with Qgen

3. Conclusions

The GAMMA+ code was validated and verified for the natural circulation conditions. The MSR system has special characteristics that the circulating fluid has heat generation whereas the solid fuel generates heat for the other type of reactor. At first, the experimental data of the $Ra=1.89\times10^5$ condition was validated. Then, the numerical comparisons were conducted for the air and fuel salt fluid with the CFX S/W. The calculated results are matched reasonably. More studies for various conditions will be conducted to assess the GAMMA+ code capabilities for the MSR operating condition.

Acknowledgements

This work was supported by Korea Research Institute for defense Technology planning and advancement (KRIT) grant funded by the Korea government (DAPA (Defense Acquisition Program Administration)) (KRIT-CT-22-017, Next Generation Multi-Purpose High Power Generation Technology (Liquid Fueled Heat Supply Module Design Technology), 2022)

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