Validation of GAMMA+ code for SFR application

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1. Introduction

The GAMMA+ code was developed in the Korea Atomic Energy Research Institute (KAERI) for the best-estimate system transient analysis of the gas-cooled reactors. Recently, the code has been updated for Sodium-cooled Fast Reactor (SFR) application. Sodium property, empirical correlations for sodium convective heat transfer, core reactivity feedback models, etc. have been added in GAMMA+ code to include the SFR system features.

In 2021, a validation program of the GAMMA+ code for the SFR application was initiated at KAERI. The two-year program is largely divided into a validation by separate effect test results and a validation by integral effect test results. The GAMMA+ code validation using the separate effect test results is currently underway. Accordingly, in this proceeding, the GAMMA+ validation program is briefly introduced, and several preliminary validation results are presented.

2. Validation Program of GAMMA+ Code

2.1 GAMMA+ Code

The GAMMA+ code has been developed as a system best-estimate analysis tool to predict the thermal and fluid flow behaviors during the anticipated as well as postulated transients for High Temperature Gas-cooled Reactors (HTGR) [1]. In particular, the code can predict the molecular diffusion and chemical reactions at the fluid bulk and the wall surface, induced by the air and steam ingress accidents. In addition the code has the capabilities for multi-dimensional analyses of the fluid flow and heat conduction, to well simulate the local flow circulation effect as well as the local temperature distributions in the core structures and thick walls.

In order to use the GAMMA+ code for transient analysis of SFR, the code has been updated by accommodating the SFR system features. Thermal-fluidic properties of sodium were added in the property database. Convective liquid metal heat transfer correlations, including Lyon-Martinelli, Graber-Rieger, and Schad-modified correlations, were employed to calculate the heat transfer capability of the heat exchangers and core for SFR. Also, the core reactivity feedback models for SFR were added considering the fuel axial expansion, core radial expansion, and CRDL/RV expansion.

2.2 Validation Plan of GAMMA+ Code

Table I shows the two-year GAMMA+ validation plan in progress at KAERI. All the available test results relevant to the SFR technology were collected for the validation [2]. At the first phase in 2021, the validation of the basic thermal-fluidic phenomena and separate effect tests is underway. At the second phase in 2022, validation of the integral effect tests is planned to be conducted.

Table I: Validation plan of GAMMA+ for SFR application

Year	Plan	Validation items
2021 (Phase-1)	Validation of basis thermal-fluidic phenomena	Sodium fill and drain
		Manometer oscillation
		Startup/shutdown transient
		Thermal conduction in fluid
		Heat transfer transient in a closed loop
	Validation of separate effect tests	Pressure drop at core (subassembly)
		STELLA-1 DHX heat transfer
		STELLA-1 AHX heat transfer
		JOYO FHX heat transfer
		PFBR FHX heat transfer
		SELFA FHX heat transfer
		JOYO IHX heat transfer
		PFBR SG heat transfer
		MONJU SST experiment
2022 (Phase-2)	Validation of integral effect tests	EBR-II SHRT tests
		Phenix EOL natural circulation
		STELLA-2 experiments
		FFTF LOFWOS tests

3. Preliminary Validation Results

In this section, several preliminary validation results that have been obtained so far are introduced. Comparison study between the experimental steady-state results and GAMMA+ calculation results on STELLA-1

DHX, JOYO IHX, PFBR FHX, and SELFA FHX is explained.

3.1 STELLA-1 DHX Heat Transfer

Fig. 1 displays an image of the DHX of STELLA-1 and Table II represents its design specification. The sodium-to-sodium heat exchanger was modeled with 30 cells at active heat transfer region using GAMMA+. The validation was carried out by comparing the outlet temperatures of the shell- and tube-sides and the thermal power, that is the heat transfer rate. Sixteen experimental test cases were used for the validation. Figs. 2 and 3 show a good agreement between the experimental results and calculation results. The discrepancies in the outlet temperatures and heat transfer rates did not exceed a deviation band from −1.36% to 1.04%, and a deviation band from −7.23% to 2.24%, respectively.

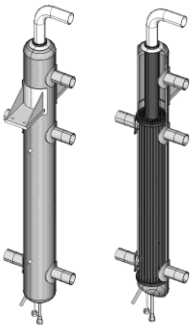

Fig. 1. STELLA-1 DHX [3].

Table II: Major design specification of STELLA-1 DHX

Parameter	Design value
Heat exchanger type	Shell-and-tube, straight-tube
Tube arrangement	Triangular lattice
No. of tubes	42
Tube outer diameter (mm)	21.7
Tube thickness (mm)	1.65
Tube pitch (mm)	32.6
Effective tube length (m)	1.73
Material	Mod.9Cr-1Mo

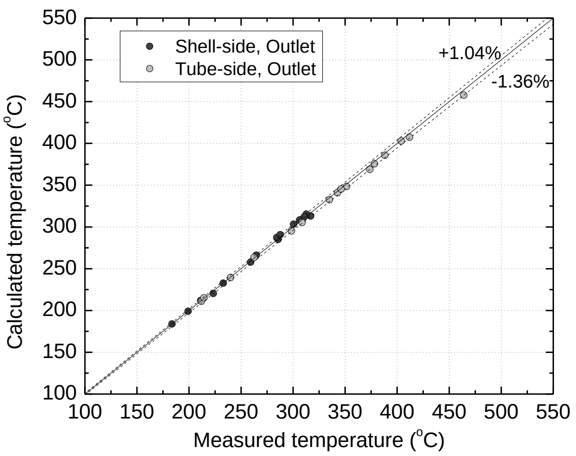

Fig. 2. Validation of outlet temperatures in STELLA-1 DHX.

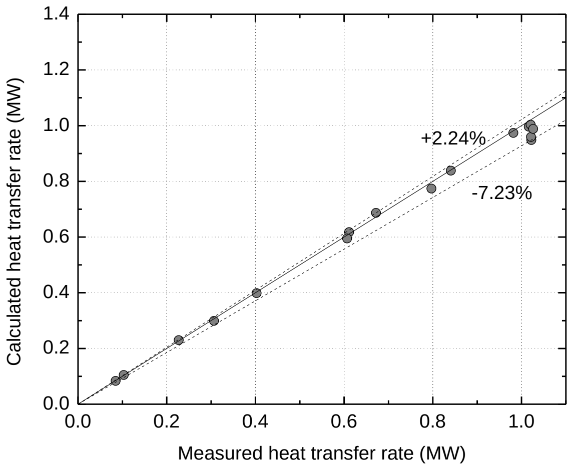

Fig. 3. Validation of heat transfer rates in STELLA-1 DHX.

3.2 JOYO IHX Heat Transfer

Fig. 4 displays an image of the IHX of JOYO and Table III represents its design specification. The sodium-to-sodium heat exchanger was modeled with 30 cells at active heat transfer region using GAMMA+. 39 experimental test cases were used for the validation. Figs. 5 and 6 show a good agreement between the experimental results and calculation results. The discrepancies in the outlet temperatures and heat transfer rates did not exceed a deviation band from −1.8% to 1.4%, and a deviation band from −4.3% to 8.1%, respectively.

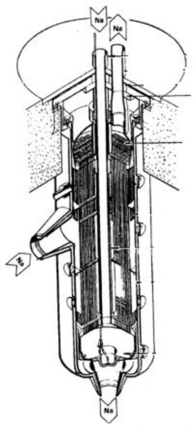

Fig. 4. JOYO IHX [4].

Table III: Major design specification of JOYO IHX

Parameter	Design value
Heat exchanger type	Shell-and-tube, straight-tube
Tube arrangement	Triangular lattice
No. of tubes	1812
Tube outer diameter (mm)	22.2
Tube thickness (mm)	1.2
Tube pitch (mm)	31
Effective tube length (m)	2.817
Material	SST 304

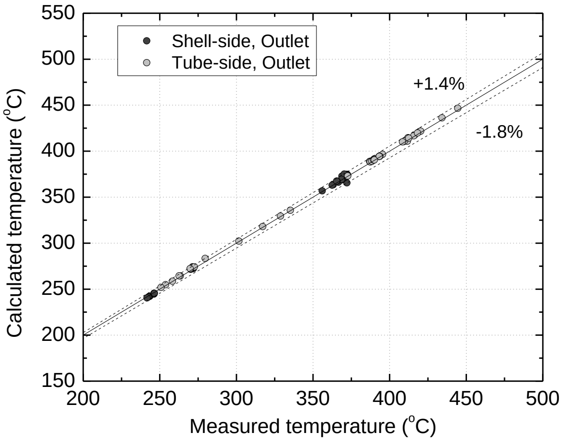

Fig. 5. Validation of outlet temperatures in JOYO IHX.

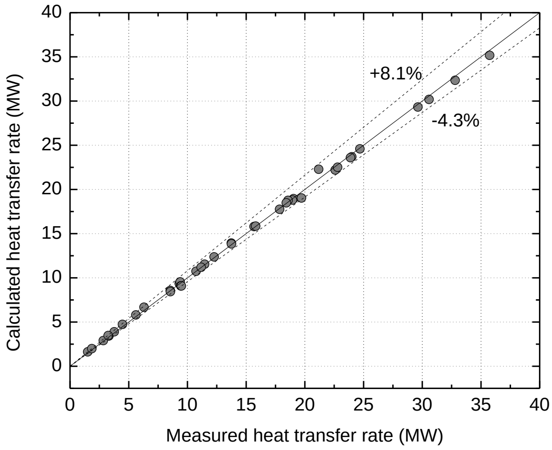

Fig. 6. Validation of heat transfer rates in JOYO IHX.

3.3 PFBR FHX Heat Transfer

Fig. 7 displays an image of the FHX of PFBR and Table IV represents its design specification. The sodium-to-air heat exchanger was modeled with 30 cells at active heat transfer region using GAMMA+. Eight experimental test cases were used for the validation. Figs. 8 and 9 show a good agreement between the experimental results and calculation results. The discrepancies in the outlet temperatures and heat transfer rates did not exceed a deviation band from -7.8% to 1.4%, and a deviation band from −8.6% to -1.8%, respectively.

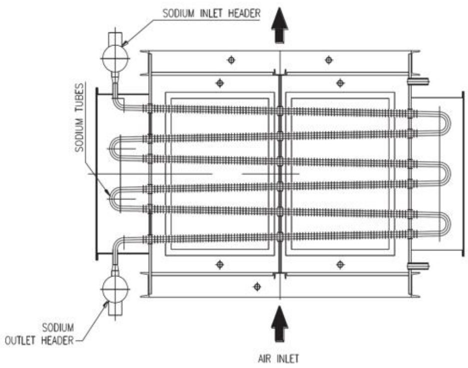

Fig. 7. PFBR FHX [5].

Table IV: Major design specification of PFBR FHX

Parameter	Design value
Heat exchanger type	Shell-and-tube, Finned-tube type
Tube arrangement	6 passes serpentine
No. of tubes	22
Tube outer diameter (mm)	38.1
Tube thickness (mm)	2.6
Longitudinal pitch (mm)	53.0
Transverse pitch (mm)	70.0
Fin height (mm)	13.0
Fin thickness (mm)	1.22
Fin pitch (mm)	5.1059

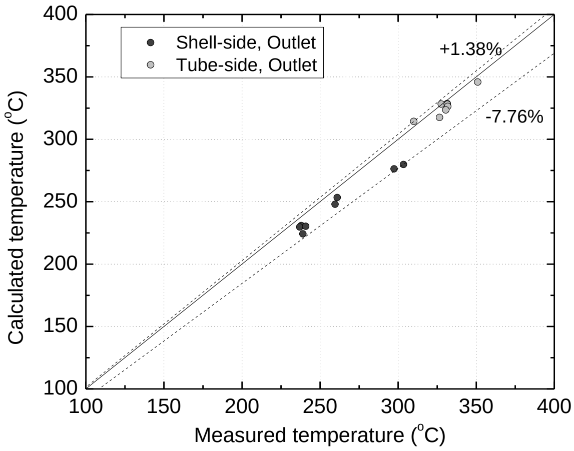

Fig. 8. Validation of outlet temperatures in PFBR FHX.

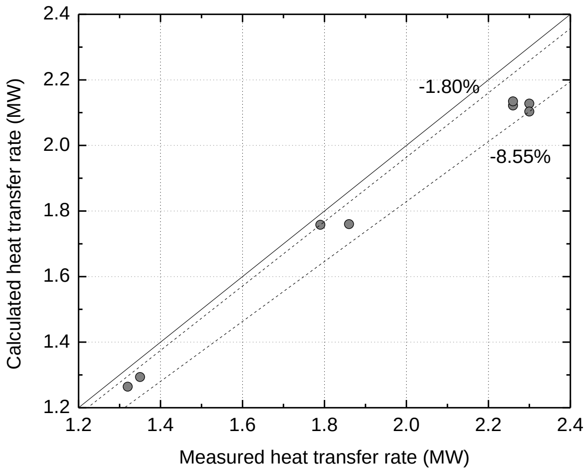

Fig. 9. Validation of heat transfer rates in PFBR FHX.

3.4 SELFA FHX Heat Transfer

Fig. 10 displays an image of the FHX of SELFA and Table V represents its design specification. The sodium-to-air heat exchanger was modeled with 39 cells at active heat transfer region using GAMMA+. 21 experimental test cases were used for the validation. Figs. 11 and 12 show a good agreement between the experimental results and calculation results. The discrepancies in the outlet temperatures and heat transfer rates did not exceed a deviation band from −3.1% to 3.2%, and a deviation band from −13.3% to -0.6%, respectively.

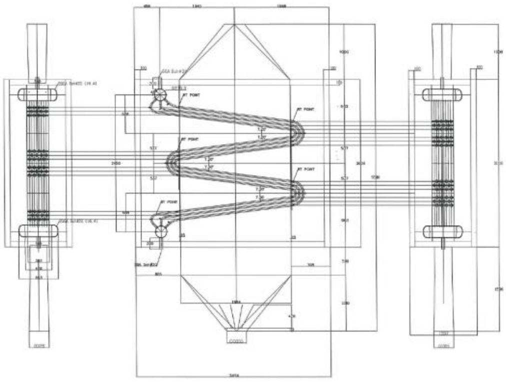

Fig. 10. SELFA FHX [6].

Table V: Major design specification of SELFA FHX

Parameter	Design value
Heat exchanger type	Shell-and-tube, Finned-tube type
Tube arrangement	4 passes serpentine
No. of tubes	21
Tube outer diameter (mm)	34.0
Tube thickness (mm)	1.65
Longitudinal pitch (mm)	69.7
Transverse pitch (mm)	76.8
Fin height (mm)	15.0
Fin thickness (mm)	1.5
Fin pitch (mm)	4.85

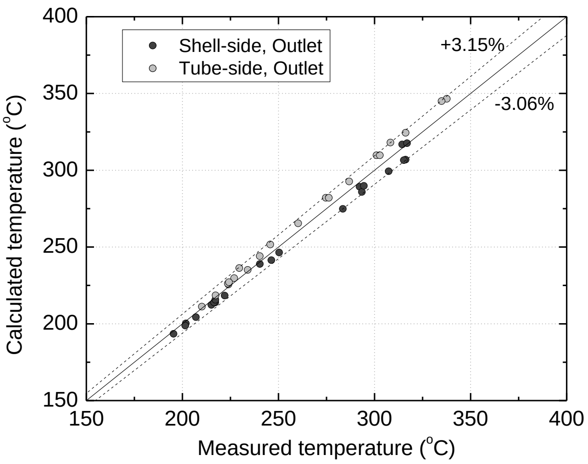

Fig. 11. Validation of outlet temperatures in SELFA FHX.

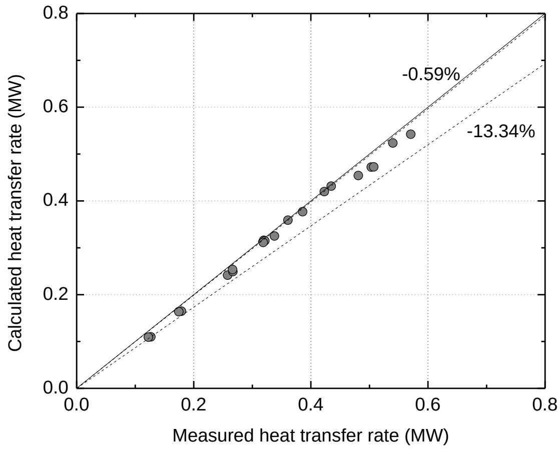

Fig. 12. Validation of heat transfer rates in SELFA FHX.

4. Conclusions

To employ the GAMMA+ code for transient analysis of SFR, the code has been updated by accommodating the SFR system features. In 2021, KAERI began to conduct the validation of GAMMA+ for SFR application according to the GAMMA+ validation program. It was shown that the experimental results agree well with the GAMMA+ calculation results, as the validation with separate effect test results is in progress. The GAMMA+ validation work is going to be finished in 2022, and then GAMMA+ is expected to be a safety analysis tool for SFR-type SMR development project.

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REFERENCES

[1] H. Lim, GAMMA+1.0 Volume II: Theory Manual, KAERI/TR-5728/2014, 2014.

[2] T. Jeong, Safety Analysis Code MARS-LMR Validation Report, SFR-960-DS-464-006 Rev.01, 2016.

[3] J. Hong, J. Lee, J. Eoh, Study on Convective Heat Transfer Correlations for Sodium-to-Sodium Heat Exchanger Based on STELLA-1 Experimental Results, Nuclear Engineering and Design, Vol. 371, 110963, 2021.

[4] T. Nanashima et al., JOYO Start-up Test Report; PT-12 Heat Transfer Characteristics of IHX and DHX, PNC TN941 79-128, 1979.

[5] V. Vinod et al., Experimental Evaluation of Sodium to Air Heat Exchanger Performance, Annals of Nuclear Energy, Vol. 58, pp. 6-11, 2013.

[6] H. Kim, SELFA FHX Heat Transfer Performance Test Result Report, SFR-710-TF-458-023 Rev.01, 2017.