Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Verification of the thermal-hydraulic performance analysis code for the integrated steam generators in SFR (I)

Seyun Kim*, Bo Young Choi, Jae-Hyuk Eoh, Eui Kwang Kim, Jong-Hyun Choi, Seong-O Kim
Fluid Sys. Eng. Div., KAERI, 150 Deokjin-Dong, Yuseong-Gu, Deajeon, Korea, 305-353, seyunkim@kaeri.re.kr

1. Introduction

In a SFR (Sodium-cooled Fast Reactor), the possibility of a water/steam leak into the sodium in a steam generator and a violent sodium-water reaction (SWR) is indispensable. To resolve the increase of construction costs for the safety of a reactor system due to a safety system, a new concept of a steam generator system should be developed. Recently, the concept of a double tube bundle steam generator (DTBSG) was proposed [1]. DTBSG removes the possibility of a SWR by a double installation of heat transfer tube bundles in a SG. The thermal-hydraulic performance analysis code, ISGA (Integrated Steam Generator Analyzer) was developed for three types of DTBSG, that is integrated double region, integrated single region and radially separated bundle types [2]. To verify ISGA code and to confirm the viability of the concept, an experimental research has been carried out. In the three types of bundle, experiments were performed. The performance characteristics of the integrated steam generator were verified with experimental data in various operation conditions.

2. Numerical analysis code

ISGA computer code was developed to analyze the thermal-hydraulic performance of three types of proposed DTBSG concepts. In the one-dimensional analysis, homogeneous two-phase model was used for the water/steam side. Feasibility of the DTBSG was shown by comparing it with an analytical solution of heat exchangers [2]. The heat from the hot tube is transferred to the shell side of steam generator and the heat is transferred to the cold tube through the tube wall.

Kalish-Dwyer convection heat transfer model for shell side and Mori-Nakayama model for helical tube side of DTBSG are used in analysis. The fouling effect was ignored in tube inner wall. Wood Metal (Pb-Sn-Cd-Bi) is used as a medium liquid metal and the properties are measured [3].

3. Verification of code

3.1 Experimental conditions

The experimental conditions are established to confirm the feasibility and heat transfer characteristics of DTBSG concepts [4]. The inlet temperatures of hot and cold fluids are about 150°C and 100°C respectively. The heat capacity rates are 0.1~1 [kJ/s-K] for hot and cold flows and 0.01~0.1 [kJ/s-K] for medium flow.

3.2 Sensitivity analysis

In the convection heat transfer analysis of shell and tube side, widely used several heat transfer models were adopted [5, 6]. To evaluate the sensitivity of analysis system, a calculation with alternative convection heat transfer model for shell and tube side was carried out. The uncertainty comes from the convection heat transfer correlations of shell side is larger than that of tube side when the total heat transfer rates are compared with reference computational condition in which above-mentioned heat transfer models were used as shown in Table 1. The sensitivity of convective heat transfer coefficient of shell and tube side on total heat transfer rate are presented in the Table 1 and the absolute values of the differences from reference condition are in similar range. The verification study should be focused on the evaluation of the heat transfer model for shell side.

Table 1. Sensitivity study on heat transfer models

		Shell	Tube	Shell	Tube
		Lubarsky-Kaufman	Seban-McLaughlin	+10% h	+10% h
Integrated single-region	**hot**	-10.0%	-0.6%	1.7%	1.2%
	medium	-9.9%	-0.4%	1.4%	1.2%
	cold	-11.8%	-0.8%	2.1%	1.4%
Integrated double-region	**hot**	-34.9%	-1.0%	1.9%	2.2%
	medium	-37.5%	-0.9%	2.1%	2.5%
	cold	-34.9%	-1.0%	1.9%	2.2%
Radially separated	**hot**	-8.8%	-0.5%	2.0%	1.5%
	medium	-8.8%	-0.5%	2.1%	1.5%
	cold	-8.8%	-0.5%	2.1%	1.5%

To investigate the effect of wood metal properties, calculations were carried out in the conditions of ±10% of change in heat capacity and conductivity. With ±10% deviation of density and viscosity of wood metal, the total heat transfer rate are rarely changed. The heat transfer rate is less sensitive to the properties in the radially separated type DTBSG than in integrated type DTBDG as presented in Table 2, because the heat is mainly transported by the convection heat transfer rather than the conduction heat transfer which is less dependent to wood metal properties in separated type DTBSG. In integrated type DTBSG, the effects of properties are large in the case of high heat capacity rate of medium fluid. However, in the view point of total heat transfer rate, the effect of ±10% of property deviation is negligible with ±2.5% uncertainty in integrated and separated type of DTBSG.

Table 2. Sensitivity study on wood metal properties

		Heat capacity		Conductivity	
		-10%	+10%	-10%	+10%
Integrated single-region	hot	-1.5%	0.8%	-1.0%	0.9%
	medium	-6.3%	5.4%	-1.0%	0.9%
	cold	1.9%	-2.2%	-1.2%	1.0%
Integrated double-region	hot	-0.4%	0.3%	-2.4%	2.1%
	medium	-9.5%	9.4%	-2.7%	2.3%
	cold	0.2%	-0.2%	-2.4%	2.0%
Radially separated	hot	-1.1%	0.5%	-1.4%	1.1%
	medium	-1.1%	0.5%	-1.3%	1.1%
	cold	-1.0%	0.5%	-1.3%	1.1%

3.3 Temperature distributions

In the three candidate type of DTBSG, the calculated temperature profiles in axial direction were compared to the measured temperature profiles. For the integrated double region type DTBSG and the radially separated DTBSG, temperatures are presented in two different bundle regions, i.e. inner and outer regions as depicted in sub-frame of figures. The axial temperature in inner region and outer region of integrated double region type DTBSG in reference condition has almost linear profile as shown in Fig. 2 and 3. The average error of calculated temperature is 8.4% and -2.3% at inner region and outer region of reference condition respectively. In integrated single region type DTBSG, the calculated temperatures compared to the measured temperatures of two radial positions in Fig. 4. The average error of calculated temperature is -12.5%.

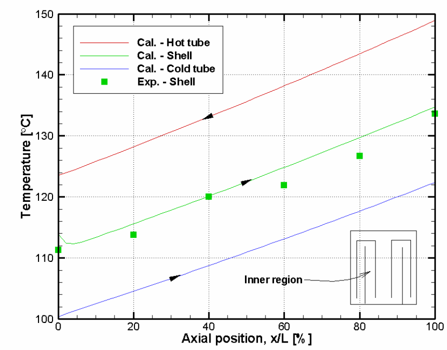

Fig. 2 Axial temperature profile of inner region of integrated double region type DTBSG

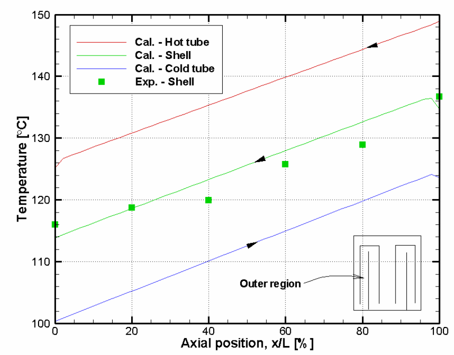

Fig. 3 Axial temperature profile of outer region of integrated double region type DTBSG

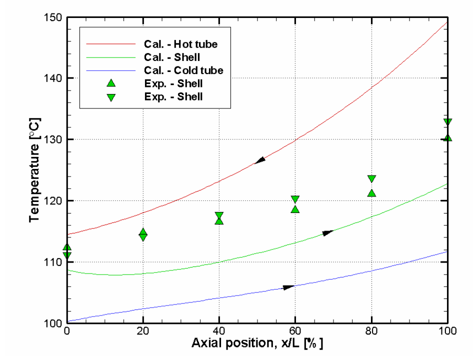

Fig. 4 Axial temperature profile of integrated single region type DTBSG

The general distribution of temperature shows good agreement with experimental data in integrated type DTBSG.

4. Conclusions

The analysis code ISGA for the performance characteristics of DTBSG was verified with experiments in various flow conditions. The sensitivity of the code for the deviation of heat transfer models, heat transfer coefficient and wood metal properties were studied and the uncertainties due to the heat transfer coefficient and properties are relatively smaller than the uncertainty results from the determination shell side heat transfer model. The shell temperature distribution of integrated type DTBSG were compared with the experimental data and the overall temperature behaviors of DTBSG were predicted well.

Acknowledgment

This research has been performed under the national nuclear mid and long-term R&D program sponsored by the Ministry of Science and Technology of Korea.

REFERENCES

[1] Sim, Y.S. and Kim, E.K., "Characteristics if Integrated Steam Generators for Liquid Metal Reactor," J. of the KNS, Vol. 36, pp. 127-141, 2004

[2] Kim, E.K., Sim, Y.S., Jeong, K. C. and S. O. Kim, "Development of a Thermal Hydraulic Analysis Code for a Combined Steam Generator-IHX Heat Exchanger," Proc. of KNS, 2004 Spring Meeting, Kyeong-ju, Korea, May 28, 2004

[3] Choi, J. H, Jeong, K. C., Choi, B. H. and Nam, H. Y., "Report for a IHTS simplification Experiment," LMR/ST120-TQ-01/05, KAERI, 2005

[4] Sim, Y. S., "Requirements for experiment of fundamental characteristics of integrated IHX/SG," LMR/FS100-XR-01/03, KAERI, 2003

[5] Kalish, S. and Dwyer, O. E., "Heat transfer to NaK flowing through unbaffled rod bundle," Int. J. Heat Mass Transfer, Vol. 10, pp. 1533-1558, 1967

[6] Mori, Y. and Nakayama, W., "Study on forced convective heat transfer in curved pipes," Int. J. Heat Mass Transfer, Vol. 10, pp. 37-59