A Study on Effects of Heat Transfer Correlation and Sodium Properties of TRACE Code for Liquid Metal Coolant

Yong Won Choi*, Andong SHIN, Moo-Hoon BAE, Namduk SUH, and Kwang Won SEUL
Korea Institute of Nuclear Safety, Goosong-dong, Yusong-gu, Daejeon, 19
**Corresponding author: k722cyw@kins.re.kr*

1. Introduction

In order to prepare the licensing of a prototype sodium-cooled fast reactor (SFR), regulatory audit technologies, reviewing the safety of system of SFR must be secured. Because of unique SFR characteristics, another design methodology is required to be used for licensing application instead of conventional methodologies that were used in water reactors. Hence, the project of the name of "Development of Regulatory Audit Technology for System Safety of Sodium-cooled Fast Reactors" is being performed by KINS. In this study, as a part of this project, the correlation relating to the heat transfer to liquid metal is reviewed and the wall-to-fluid temperature drop with the change of heat transfer correlation is analyzed. For this, the correlations for heat transfer to liquid metal are applied to TRACE. Additionally, sensitivity study for the temperature drop by change of sodium properties is performed.

1. Correlation relating to the heat transfer to liquid metal

The heat transfer to liquid metals significantly differs from the heat transfer to water. The main reason for this difference is that liquid metals have a very low Prandtl number (Pr). In other words, the contribution to the total heat transfer from the thermal conductivity (compared to the contribution from the convection) is much higher for liquid metal compared to water. Hence, a proper selection of the correlation for heat transfer to liquid metal flowing is important. For this, the researches[1],[2] for heat transfer to liquid metal were reviewed.

1.1 Review of correlation for heat transfer to liquid metal

According to the researches[1],[2] which were reviewed, the eight correlations for heat transfer to liquid metal were suggested. The correlations are as follows.

- Correlations by Dwyer and Tu (1960), Friedland and Bonilla (1961)

$$Nu = 0.93 + 10.81\mathrm{x} - 2.01x^2 + 0.0252x^{0.273}(\psi Pe)^{0.8} \qquad \text{[Eq. 1]}$$

$$Nu = 7.0 + 3.8x^{1.52} + 0.027x^{0.27}(\psi Pe)^{0.8} \qquad \text{[Eq. 2]}$$

- Correlation by Mareska and Dwyer (1964)

$$Nu = 0.93 + 10.81\mathrm{x} - 2.01x^2 + 0.0252x^{0.273}(\psi Pe)^{0.8} \qquad \text{[Eq. 3]}$$

- Correlation by Subbotin et al (1965)

$$Nu = 0.58\left(\frac{2\sqrt{3}}{\pi}x^2 - 1\right)^{0.55} Pe^{0.45} \qquad \text{[Eq. 4]}$$

- Correlation by Ushakos et al. (1977)

$$\mathrm{Nu} = 7.55\mathrm{x} - \left(\frac{20}{\mathrm{x}^{13}}\right) + \left(\frac{0.041}{\mathrm{x}^2}\right)\mathrm{Pe}^{0.56+0.19\mathrm{x}} \qquad \text{[Eq. 5]}$$

- Correlation by Borishanski et al. (1969)

$$\mathrm{Nu} = 24.15\log(-8.12 + 12.76\mathrm{x} - 3.65\mathrm{x}^2) + 0.0174\left(1 - \mathrm{e}^{-6(\mathrm{x}-1)}\right)\mathrm{B}, \qquad \text{[Eq. 6]}$$

$$\text{where } \mathrm{B} = \begin{cases} 0, & \mathrm{Pe} < 200 \\ (\mathrm{Pe} - 200)^{0.9}, & \mathrm{Pe} > 200 \end{cases}$$

- Correlation by Graber and Rieger (1972)

$$\mathrm{Nu} = 0.25 + 6.2\mathrm{x} + (0.032\mathrm{x} - 0.007)\,\mathrm{Pe}^{0.8-0.024\mathrm{x}} \qquad \text{[Eq. 7]}$$

- Correlation by Zhukov et al. (2002)

$$\mathrm{Nu} = 7.55\mathrm{x} - 14\mathrm{x}^{-5} + 0.007\,\mathrm{Pe}^{0.64+0.246\mathrm{x}} \qquad \text{[Eq. 8]}$$

- Correlation by Konstantin Mikityuk (2009)

$$\mathrm{Nu} = 0.047\left(1 - \mathrm{e}^{-3.8(\mathrm{x}-1)}\right)(\mathrm{Pe}^{0.77} + 250) \qquad \text{[Eq. 9]}$$

Where, Pe is peclet number, x is pitch to diameter ratio and ψ means ratio of eddy diffusivity of heat to eddy diffusivity of momentum.

Also, in exiting research[1], the quality of each correlation was evaluated for the whole range of the test data base even if the pitch to diameter ratio and/or Peclet numbers in the experiment were out of the range recommended for that specific correlation. As the results, it was evaluated that the three correlations have the highest accuracy. The three correlations are as follows;

1) Correlation by Ushakos,
2) Correlation by Graber and Rieger
3) Correlation by Konstantin Mikityuk.

1.2 Sensitivity study of the wall-to-fluid temperature difference to the heat transfer correlation

In this study, the sensitivity study of the wall-to-fluid temperature difference to the heat transfer correlation is performed for confirmation of application on TRACE code and effect of heat transfer correlation. Also, TRACE code was modified for application of the three correlations. For this sensitivity study, the simple node composition is made. Fig.1 shows the node composition and it is comprised of 1 pipe of 13cells, 1 heat structure, 1 fill and 1 break. This composition of node is for outer core of DEMO-600. Therefore, initial condition of each node is equal to that of outer core of DEMO-600. The major initial conditions are as follows:

Coolant: Na
Mass flow rate (inlet): 3466.6 kg/s (637.14K, $3.82e^5$Pa)
Outlet (Break) Condition: 693.34K, $3.82e^5$Pa
Power: $7.39693e^8$ W

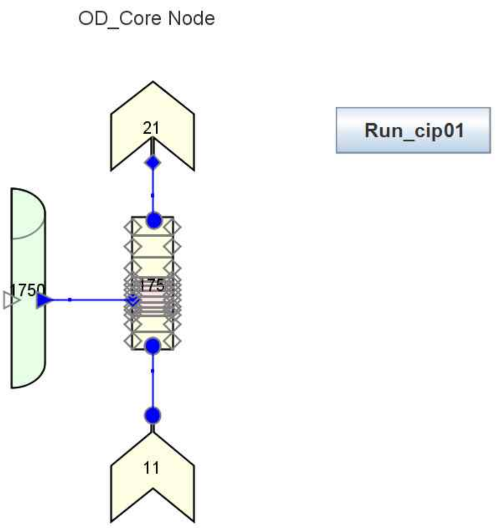

Fig. 1. Composition of node for sensitivity study

Fig.2 shows the results of sensitivity analysis of the wall-to-fluid temperature drops to the heat transfer correlation. According to these results, Mikityuk Correlation has the maximum value of wall-to-fluid temperature drop. Also KAERI correlation in Fig.2 means the correlation(Subbotin correlation) for heat transfer to liquid metal in MARS-LMR[2].

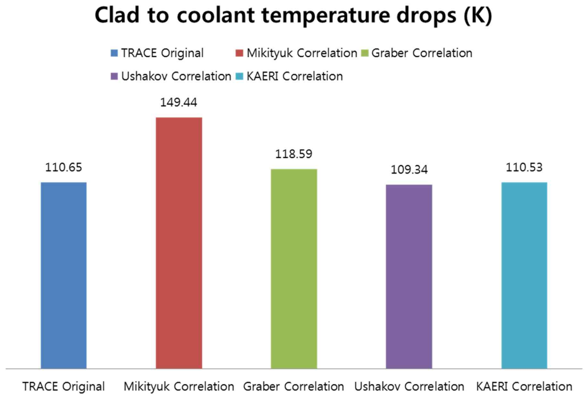

Fig. 2. The result of sensitivity analysis of the wall-to-fluid temperature difference to the heat transfer correlation

2. Sensitivity study for the effect on heat transfer to the change of sodium properties

In this study, as preliminary study, the applicability of TRACE code for changes of sodium properties is evaluated. For this, the sensitivity analysis for the effect on heat transfer to the change of sodium properties is performed. Use of different sodium properties can lead to different results of heat transfer calculation. Hence, the utilization of proper properties is important. So, the sodium properties between TRACE code and MARS-LMR are compared. The result is that the liquid specific heat at constant volume in TRACE code differs from that in MARS-LMR. Accordingly, sensitivity analysis to the change of liquid specific heat at constant volume is performed. Fig. 3 shows wall-to-fluid temperature difference to the change of liquid specific heat and Fig.4 shows outlet temperature and difference of temperature between outlet and inlet. According to the results, wall-to-fluid temperature drop is decreased with decrease of liquid specific heat constant value. It means to be applied on TRACE properly.

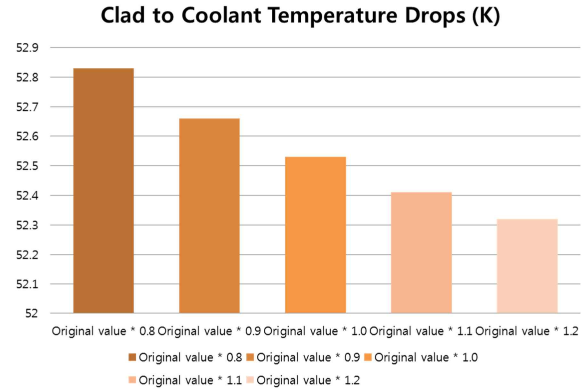

Fig. 3. The result of sensitivity analysis of the wall-to-fluid temperature difference to the change of liquid specific heat

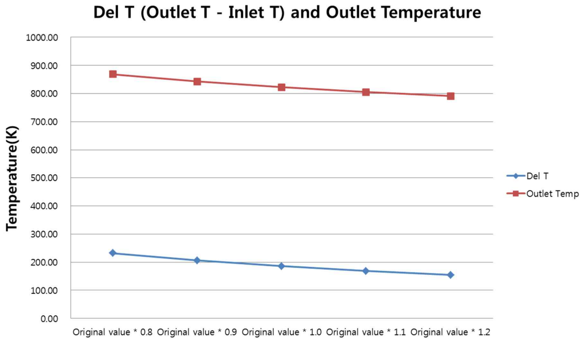

Fig. 4. The difference of temperature between outlet and inlet to the change of liquid specific heat

3. Conclusions

In this study, as preliminary study, the heat transfer correlations for liquid metal coolant are reviewed and the sensitivity analysis to the changes of correlation and liquid specific heat is performed. The results show the difference of heat transfer with correlation and properties. Also, through this study, the applicability on TRACE for changes of correlation and properties is evaluated. This research could be contributed to development of regulatory audit technology for system safety of sodium-cooled fast reactors.

REFERENCES

[1] Konstantin Mikityuk, "Heat Transfer to liquid metal: Review of data and correlations for tube bundles" Nuclear Engineering and Design, Dec. 2008.

[2] KAERI, "Development of MARS-LMR and Steady-State Calculation for KALIMER-600", KAERI/TR-3418/2007, May 2007.