Simulation of the VISTA SG heat transfer experiment using MIDAS/SMR

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1. Introduction

As the SMART plant was designed with the helical type tubes in the steam generators, the heat transfer model in that geometry has been implemented in the TASS/SMR-S code [1] and used for the safety analysis. The same correlation was implemented in the MIDAS/SMR [2], which is being used for the severe accident analyses, to model heat transfer at the steam generators. In this study, the VISTA SG experiment [1] with the helical steam generator tube was simulated with MIDAS/SMR to compare the heat transfer rates through the helical tube.

2. Helical SG U-tube heat transfer model

2.1 Implemented heat transfer correlations [1]

The following correlation is for the primary of the helical tube under the sub-cooled water condition:

$$h = C \cdot \left(\frac{k}{D}\right) \cdot Re_f^m \cdot Pr_f^{0.36} \cdot \left(\frac{Pr_f}{Pr_w}\right)^{0.25}$$

Under the subcooled or superheat conditions for the secondary side of the helical tube, the following correlations are used:

$$h = \begin{cases} \frac{1}{26.2} \cdot \left(\frac{k}{d_i}\right) \cdot \frac{Pr}{(Pr^{2/3} - 0.074)} Re^{4/5} \left(\frac{d_i}{D_c}\right)^{1/10} \left\{1 + \frac{0.098}{[Re(d_i/D_c)^2]^{1/5}}\right\} & \text{for } Pr \simeq 1 (gases) \\ \frac{1}{41.0} \cdot \left(\frac{k}{d_i}\right) \cdot Pr^{0.4} Re^{5/6} \left(\frac{d_i}{D_c}\right)^{1/12} \left\{1 + \frac{0.061}{[Re(d_i/D_c)^{2.5}]^{1/6}}\right\} & \text{for } Pr > 1 (liquids) \end{cases}$$

where k = water or vapor conductivity [W/m-k]
d_i = U-tube inside diameter [m]
D_c = SG helical coil effective diameter[m]

Finally, the heat transfer coefficient under the forced convection two-phase condition can be defined as follows:

$$h = S \cdot h_b + F \cdot h_c$$

The heat transfer coefficient is defined with the combination of h_b and h_c and they are:

$$h_b = 0.00122 \cdot \left[\frac{k_f^{0.79} C_{pf}^{0.45} \rho_f^{0.49}}{\sigma^{0.5} \mu_f^{0.29} h_{fg}^{0.24} \rho_g^{0.24}}\right] \cdot \Delta T_{sat}^{0.24} \cdot \Delta P_{sat}^{0.75}$$

$$h_c = 0.023 \cdot \left(\frac{k}{d_i}\right) \cdot (1-x)^{0.8} \cdot Re^{0.85} \cdot Pr^{0.4} \cdot \left(\frac{d_i}{D_c}\right)^{0.1}$$

Also the S and F are defined using the Martinelli's parameter:

$$X_{tt} = \left(\frac{\rho_g}{\rho_\ell}\right)^{0.571} \left(\frac{\mu_\ell}{\mu_g}\right)^{0.143} \left(\frac{1}{\chi} - 1\right)$$

$$F = 2.35 \cdot (\chi_{tt}^{-1} + 0.213)^{0.736}$$

$$Re_{tp} = \frac{G \cdot (1-x) \cdot D}{\mu_f} \cdot F^{1.25} \cdot (10^{-4})$$

$$S = \begin{cases} [1 + 0.12 \cdot (Re_{tp})^{1.14}]^{-1} & Re_{tp} < 32.5 \\ [1 + 0.42 \cdot (Re_{tp})^{0.78}]^{-1} & 32.5 \le Re_{tp} \le 70 \\ 0.0797 & 70 < Re_{tp} \end{cases}$$

2.2 Modeling and Input assumptions

For the VISTA SG experimental system, only the helical SG tube part was considered in this study. The SG experimental zone was divided into two parts such as the primary and the secondary sides. The important input data for the primary side were the inlet pressure, the inlet fluid temperature and the fluid injection rate. The data for the secondary were the same as those of the primary.

The helical tube part was divided into ten control volumes in the axial direction. Hot primary fluid was poured over the outer surface of the helical tube from the top and the cold secondary fluid was injected from the bottom through the inside of helical tube.

Figure 1 shows the nodalization to simulate the VISTA reduced SG heat transfer experiment with MIDAS/SMR. While the red part means the secondary side (=tube inside), the blue means the primary (=tube outside).

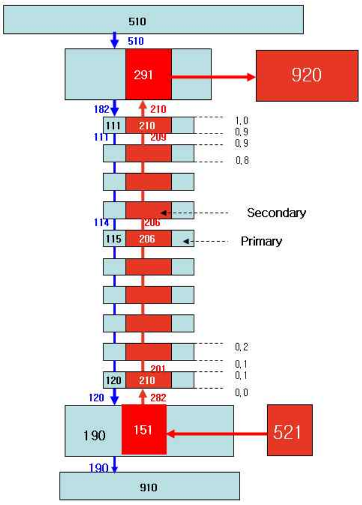

Figure 1 Nodalization for the VISTA SG experiment with MIDAS/SMR

The SG part in the VISTA SG experiment was scaled down to 1/8 compared to the one cassette size of the real SMART system. The diameter of the helical tube and its material (=inconel-690) are the same as that of the real SMART system. The experimental condition covers the pressure range from 150 bar to 169 bar for the primary side. For the secondary side, it covers from 36 bar 48 bar. The flow rates for the primary side changed from 1.02 kg/s to 4.2 kg/s. For the secondary, they were from 0.025 kg/s to 0.251 kg/s. While the inlet temperatures for the primary side ranged from 671.2 K to 682.2 K, the secondary inlet temperatures from 319.6 K to 353.0 K. Table 1 showed the important input data for simulating the VISTA SG with MIDAS/SMR.

Table.1 VISTA reduced SG heat transfer input data

parameter	input	unit
Axial height of SG active heat transfer region	1.0	[m]
Helical tube in-dia	0.0035	[m]
Helica tube out-Dia	0.005	[m]
Total coil number	12	
Total length for one coil	9.75	[m]
effective cross sectional area for the primary channel	4.188×10^{-3}	[m^2]

2.3 Simulation results.

Figure 2 showed the comparison of the results between the measured and calculated heat transfer rates from the secondary side. It was found that the predicted heat transfer rates from the secondary side were well matched with the measured data for the various experiments defined by the experimental conditions.

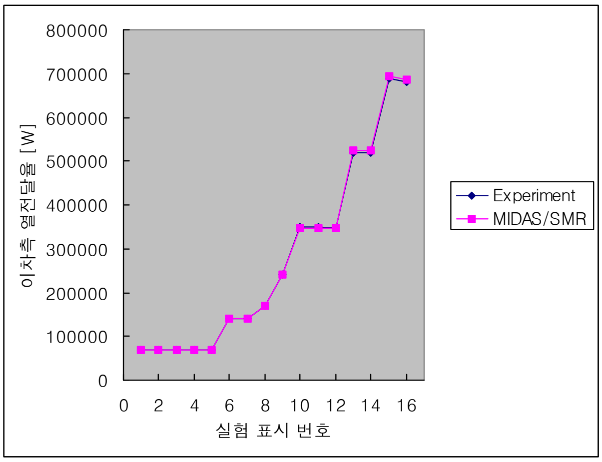

Figure 2 Comparison of Predicted SG secondary heat transfer rates with the experimental data

3. Conclusion

The heat transfer rates for the VISTA SG experiment with the helical steam generator tube were simulated with the MIDAS/SMR computer code. The code well predicted the heat transfer rates from the SG secondary side and the outlet conditions. Though more validation work is needed for the extended conditions, MIDAS/SMR can be used for the steam generator heat transfer analysis at SMART with the helical type tubes.

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