The Steady State Calculation for SMART with MIDAS/SMR

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1. Introduction

KAERI is developing a new concept of reactor that all the main components such as the steam generator, the coolant pumps and the pressurizer are located inside the reactor vessel. Before the severe accident sequences are estimated, it is prerequisite that MIDAS code predicts the steady state conditions properly. But MIDAS code does not include the heat transfer model for the helical tube. Therefore, the heat transfer models for the helical tube from TASS/SMR-S were implemented into MIDAS code [1]. To estimate the validity of the implemented heat transfer correlations for the helical tube and the input data, the steady state was recalculated with MIDAS/SMR based on design level 2 and compared with the design values.

2. Helical SG U-tube heat transfer model

2.1 Implemented heat transfer correlations for the helical SG U-tube

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

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

Re 수	C		m
	in-line	staggered	
10 - 100	0.8	0.9	0.4
100 - 1000	0.51	0.51	0.5[(1)]
1000 - 2x10^5	0.27	-	0.63
	-	0.35(a/b)$^{0.2}$	0.60[(2)]
	-	0.40	0.60[(3)]
> 2x10^5	0.021	0.022	0.84[(4)]

a=relative transverse; b=relative longitudinal
(1) Value at single tube:
bank has similar value with a single tube
(2) for a/b < 2
(3) for a/b > 2
(4) for Pr > 1

The following correlations are for the secondary side of the helcal tube under the sub-cooled or superheat conditions.

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

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

The last implemented correlation is for the secondary side under the two phase condition.

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

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

The Martinelli's parameter and its function F were defined as below.

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

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

The function of S and the Reynolds number under the two-phase condition are obtained as below.

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

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

Finally, the heat transfer coefficient under the two-phase condition can be found as follows.

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

2.2 Modeling and Input assumptions

SMART system adopts the helical tubes with the type of once-through for the steam generator. It does not require any large volume and also any pre-heater and the dryer because it uses directly the super heated steam discharging from the exit of helical tube.

To estimate the validity of the implemented heat transfer correlations for the helical tube and the input data, only the helical tube region was modeled with the boundary conditions for the both sides such as the coolant inlet flow rates, inlet coolant temperatures and pressures.

Figure 1 shows the nodalization of the SMART system for simulating the steady state condition.

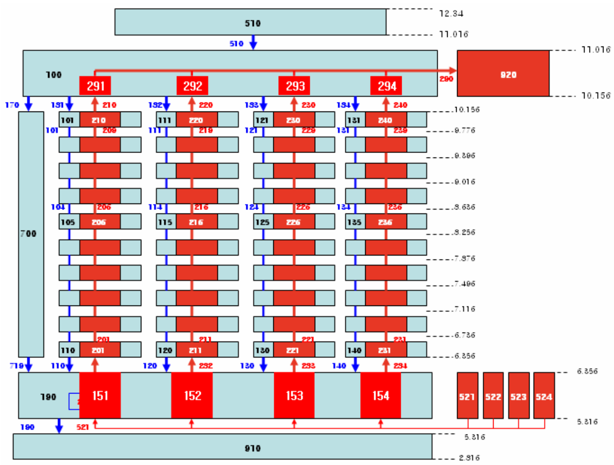

Figure 1 Nodalization of SMART system for simulating the steady state condition

2.3 Steady state calculation results.

The steady state was confirmed base on the exit conditions for the primary and secondary sides.

As the applications of these correlations to MIDAS/SMR result in under-prediction comparing to the target thermal-output of 330 MWt, multiplication factors to the correlations were used to get the steady state conditions. Figure 2 shows the comparison of the predicted thermal power before and after the code update, respectively.

Table 1 compares the predicted important parameters for the steady state conditions in the SMART system with the design data based on the design level 2.

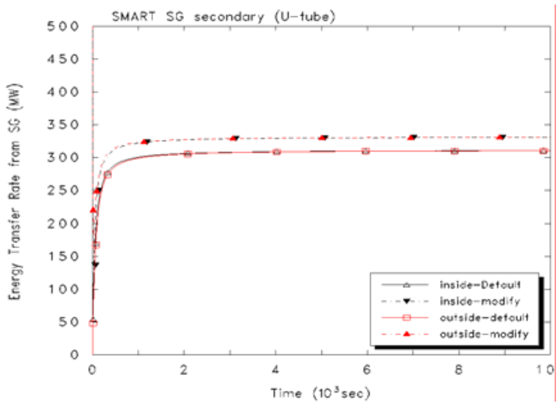

Figure 2 Predicted thermal power of SMART

Table 1 The predicted steady state conditions in SMART

System parameters	Design	Calcul
Thermal power, MWt	330.0	330.0
Primary parameters		
Primary flow rate, kg/s	2090.0	2078.5
core flow rate	2006.47	2001
bypass flow rate, kg/s	83.6	76.7
PZR pressure, MPa	15.0	14.99
PZR fluid temperature, ℃	342.13	342.15
Core pressure, MPa	15.0	15.1
SG Inlet Temperature, ℃	323.0	322.6
SG outlet Temperature, ℃	295.7	294.85
Secondary parameters		
Feed Flow rate, kg/s	160.8	160.8
Feed water pressure, MPa	6.03	5.91
Feed water Temperature, ℃	200.0	199.65
STeam line (node 128) pressure, MPa	5.2	5.2
Degree of superheat of steam, ℃	more than 30.0	32.23

3. Conclusion

MIDAS/SMR code with the heat transfer correlations for the helical tube was predicted well for the steady state at the SMART plant based on the design level 2. However the predicted pressure drop at some points showed a little difference.

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REFERENCES

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