§14. Numerical Analysis on Temperature Rise and Pressure Drop of Supercritical Helium in Cable-in-conduit Conductor of Helical Coils for Helical DEMO Reactor FFHR-d1

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A design study on the helical-type fusion reactor (FFHR) has been promoted in National Institute for Fusion Science (NIFS).[1] In the latest design for the helical DEMO reactor FFHR-d1, the maximum nuclear heating in the helical coils is estimated to be 500 W/m^3 due to the restriction of the blanket space.[2] In the case of the continuous helical coils, it has become a major issue from the aspect of cooling. In the present study, a one-dimensional numerical analysis in the longitudinal direction of the superconductor was conducted in order to evaluate the temperature rise and pressure drop of supercritical helium (SHe) in the cable-in-conduit conductor (CICC).

The main parameters were listed in Table 1. In the case of FFHR-d1, the length of one cooling path is 471 m. A numerical model is shown in Fig. 1. The circular pipe with same diameter of the center channel of the CICC was assumed as the cooling channel. While the maximum nuclear heating of 500W/m^3 was applied to 15 % of innermost layer, the basic nuclear heating of 100 W/m^3 was applied to the rest of that. SHe properties were calculated by using HEPAK© copyright Cryodata Inc. The pressure drop of SHe was evaluated by Darcy-Weisbach equation. The three kinds of equations, which were Hagen-Poiseuille, Blasius and Nikuradse equation, were applied to the coefficient of friction. A set of basic equations is shown as follow;

$$h_i = h_{i-1} + \frac{Q \cdot \Delta x_i \cdot D_{CICC}{}^2}{\dot{m}}$$

$$P_i = P_{i-1} - f_{i-1} \cdot \frac{\Delta x_{i-1}}{D_h} \cdot \frac{\rho_{i-1} \cdot u_{i-1}^2}{2}$$

where h is enthalpy, Q nuclear heating, Δx mesh spacing, D_{CICC} diameter of CICC, $\dot{m}$ mass flow rate, P pressure, f friction factor, D_h hydraulic diameter, ρ density and u velocity. SHe temperature was calculated from the pressure and the specific enthalpy, using HEPAK.

Fig. 2 shows the temperature rise and the pressure drop of SHe between the inlet and the outlet of the CICC at the innermost layer of the helical coils for the FFHR-d1 when the mass flow rate of SHe through the CICC was changed. The temperature rise decreased as the SHe mass flow increased, but the pressure drop increased. In the present study, the acceptable temperature rise and pressure drop are less than 1.0 K and 0.1 MPa, respectively. In the case of the SHe mass flow from 41g/s to 47 g/s, it was found that the design window, shown by gray rectangle in Fig. 2, was obtained.

Table 1. Main parameters of the helical coils for the helical DEMO reactor FFHR-d1.

Major radius	15.6 m
Minor radius	3.9 m
Length of a turn	157 m
Magnetic field at coil center	4.7 T
Current density	25 A/mm^2
Overall current	100 kA
Minimum distance to plasma	0.89 m
Maximum nuclear heating	500 W/m^3

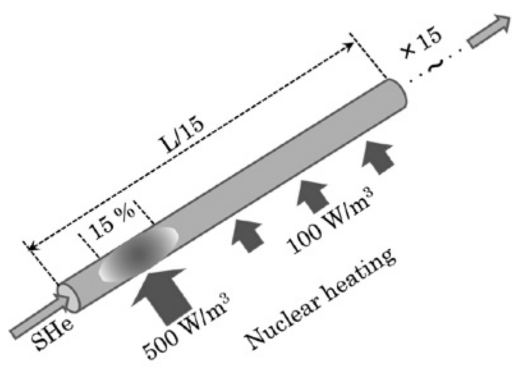

Fig. 1. Schematics of the numerical model for the CICC at the innermost layer of the helical coils.

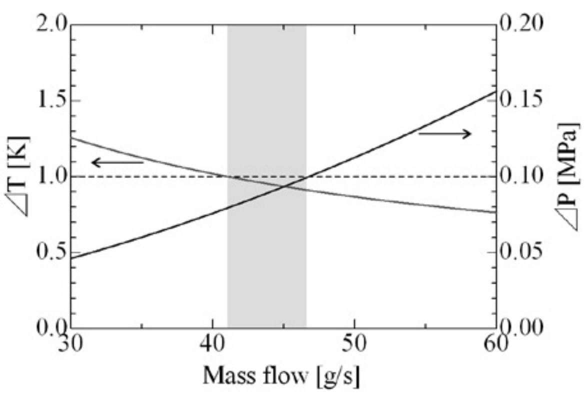

Fig. 2. Temperature rise and pressure drop of SHe between the inlet and the outlet of the CICC when the SHe mass flow through the CICC was changed.

1) A. Sagara et al., Fusion Eng. Des., **83** (2008) 1690.
2) T. GOTO et al., Plasma Fusion Res., **7** (2012) 2405084.