§20. Heat Removal Demo-research for Flibe Blanket Development

Hashizume, H., Ebara, S., Ito, S. (Tohoku Univ.),
Kunugi, T., Yokomine, T. (Kyoto Univ.),
Yuki, K. (Tokyo Univ. Sci., Yamaguchi),
Kondo, M. (Tokai Univ.),
Sagara, A., Muroga, T., Nagasaka, T.

Flibe blanket using molten salt Flibe as breeding material as well as a coolant, is one of the advanced liquid blankets for fusion DEMO reactors and its conceptual design is in progress for LHD-type fusion reactor, FFHR, to date. Although the blanket has many strong points, e.g., MHD pressure drop is negligibly small because of low electric conductivity of Flibe, there are still several issues to be solved. High melting temperature of Flibe (459 deg. C) is one of the issues because a temperature window of the blanket design is very limited due to the upper limit of temperature of the structural material (RAFS) of about 550 deg. C. In addition, it is very important from engineering point of view to demonstrate a heat removal of 1 MW/m^2 corresponding to the heat flux assumed to be imposed on the first wall of FFHR.

Regarding the melting temperature, previous studies revealed that composition change in Flibe, which was achieved by changing ratio of BeF_2 to LiF or by adding another salt such as CsF to Flibe, was effective to make it lower. In these cases, thermal and nuclear properties of the composition-changed Flibe are necessary to estimate. As for the high heat flux removal, this has been accomplished by using a sphere-packed pipe (SPP) in which a molten salt HTS as a simulant of Flibe flows. However, the detailed heat transfer characteristic of the SPP under high heat flux condition has yet to be clearly elucidated. In this study, heat transfer experiment using Tohoku-NIFS Thermal loop (TNT loop) and molten salt HTS was conducted to make an advanced heat transfer correlation available for the high heat flux case. Moreover, mixed Flibe was tested to obtain its thermal and nuclear properties.

The form of a heat transfer correlation equation is assumed to be expressed as follows.

$$\mathrm{Nu}_d = C\,\mathrm{Re}_d^{\,w}\,\mathrm{Pr}^x\left(\frac{\mu_b}{\mu_w}\right)^y\left(\frac{k_s}{k_f}\right)^z \qquad (1)$$

where Nu_d and Re_d correspond to Nusselt and Reynolds numbers based on the diameter of the sphere packed in a pipe as the length scale, respectively, and Pr is Prandtl number using thermal properties at bulk temperature. The symbols of μ_b and μ_w are viscosities at bulk and wall temperatures, respectively, and k_s and k_f are thermal conductivities of the packed sphere and fluid, respectively. In the experiment, the diameter of the packed spheres was a half of the pipe. In the equation, the term of $(\mu_b/\mu_w)^y$ expresses the influence of local temperature difference induced by high wall heat flux and $(k_s/k_f)^z$ expresses the fin effect, i.e., effect of high thermal conductivity of solid spheres to heat transfer in the SPP. By using different material of the packed spheres, SS304 and Al, whose thermal conductivities were largely different, it was found that the fin effect hardly appeared. On the other hand, the effect of viscosity change clearly appeared in the experiment. And as shown in Fig. 1, the index was determined as 2.2.

As for the index of Pr, change in Pr in the experiment was too small (24-27) to determine a reliable value. For this reason, the index was determined as 0.3106 by using previous experimental data obtained from heat transfer experiments using three kinds of silicon oils with largely different Pr (23-150). The remaining index and constant were determined by regression analysis, and the resultant expression is shown as follows.

$$\mathrm{Nu}_d = 0.2424\,\mathrm{Re}_d^{\,0.7595}\,\mathrm{Pr}^{0.3106}\left(\frac{\mu_b}{\mu_w}\right)^{0.22} \qquad (2)$$

Figure 2 shows the correlation equation together with the experimental data obtained when two values of wall heat flux, 0.2 and about 1.0 MW/m^2 were imposed. The equation shows good agreement with the data whether the wall heat flux is high or low.

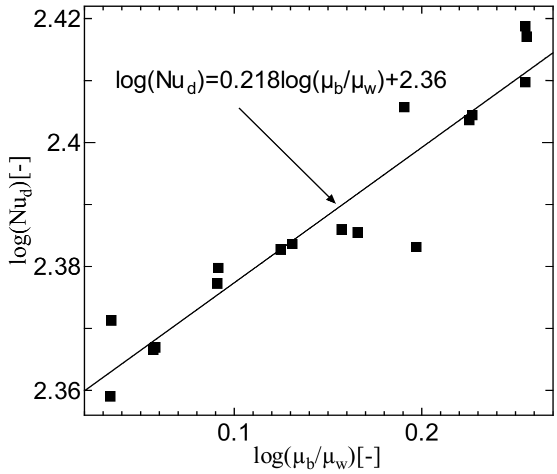

Fig. 1 Influence of viscosity change on the heat transfer characteristic

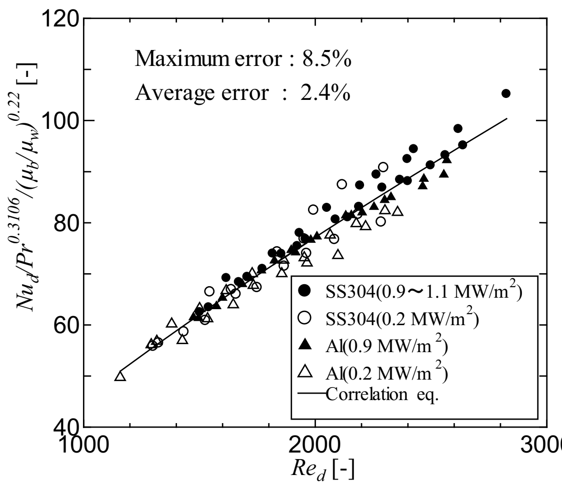

Fig. 2 Heat transfer characteristic expressed by a heat transfer correlation equation