§2. Thermo-mechanical Evaluation for Flibe Test Blanket Module

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In order to verify the possibility of Flibe blanket system, it becomes crucial to demonstrate the design of Flibe blanket not only for demo reactor but for TBM in the ITER system. The final goal of this study is to propose the Flibe TBM system satisfying allowable maximum temperature required for the structural material (550 $^\circ C$) and show the way to the blanket system for demo reactor.

At first, the empirical correlation in terms of heat transfer corresponding to relatively high Re and Pr numbers was derived based on the experimental results for sphere-packed-pipe using water and silicon oil as working fluid. The relation is given by

$$Nu_D = C(f_w Re_w)^a (Pr)^b [\arctan\{(D/d)-1+\tan(1)\}]^c \quad (1)$$

(820<Re<33500, 5.1<Pr<31.8, 1.3<D/d<3.0)

where D and d are diameters of pipe and sphere, respectively, and fw and Rew are wall modified friction coefficient and wall modified Reynolds number, respectively. The coefficients in the equation are summarized in table 1.

D/d	*C*	*a*	*b*	*c*
3.0, 2.0	0.5912	0.6443	0.3931	4.0466
2.2, 1.3	1.2648	0.6202	0.3931	-0.1598

Based on the newly obtained correlation, thermo-mechanical analysis was performed to demonstrate there exist some design windows for Flibe TBM in ITER. The temperature condition imposed as allowable maximum temperature in the structural material is assumed to be 550 $^\circ C$. Other conditions assumed in this analysis are 0.5 MW/m^2 of heat flux, 20 W/m/K of thermal conductivity of the structural material, 30 mm of tube inner diameter, 2 mm of the tube thickness and 1m length of the tube. Under these condition, the temperature difference induced across the wall thickness is 50 $^\circ C$ and therefore the allowable temperature on the heat removal surface at the outlet becomes 500 $^\circ C$. This means the following equation should be satisfied;

$$T_{melt} + \Delta T_{outlet-inlet} + \Delta T_{wall-Flibe} < 500^\circ C \qquad (2)$$

or $\Delta T_{outlet-inlet} + \Delta T_{wall-Flibe} < 500^\circ C - T_{melt}$ (3)

Here $T_{melt}, \Delta T_{outlet-inlet}, \Delta T_{wall-Flibe}$ are melting temperature of Flibe, temperature increase between inlet and outlet, and temperature jump between heat removal surface and bulk Flibe temperature, respectively. The Flibe to be used in future fusion reactor is composed of 66% LiF and 34% Be$_2$F, whose melting temperature is 459 $^\circ C$. This fact clearly indicates it impossible to satisfy eq,(3) under the present assumed condition. On the other hand, by changing the composition ratio of Be$_2$F in Flibe from 34% to 50%, it becomes possible to reduce the melting point of Flibe. In this case, however, the Pr number contrarily increases to result in degradation in the heat transfer performance. Therefore, there might exist optimum design windows in terms of Be$_2$F ratio. Figure 1 shows the right hand side terms and right hand side terms in eq.(3) when the Be$_2$F is changed. Form the result, the right hand side terms does not change so much with varying the Be$_2$F ratio when the velocity is kept constant. By comparing the cases of D/d=3.0 and D/d=1.3, the heat transfer performance of D/d=3.0 is better than that of D/d=1.3 since the spheres corresponding to D/d=3.0 are packed more densely. From the results shown in fig.1, it can be seen that eq.(3) will be satisfied when the ratio of Be$_2$F is more than 45% in case of D/d=1.3 and u=0.5m/s, more than 37% in case of D/d=1.3 and u=1.0 m/s, more than 40% in case of D/d=3.0 and u=0.5 m/s, or more than 35% in case of D/d=3.0 and u=1.0m/s. While by increasing the ratio of Be$_2$F, the temperature margin becomes larger, the pressure drop induced in the sphere-packed tube increases as shown in fig.2. With considering the pressure drop, the attractive design point might be achieved by using 50% Be$_2$F Flibe flowing with 1 m/s velocity in D/d=1.3 sphere-packed tube. In this case the pressure drop is 0.4 MPa/m and temperature margin is 70 $^\circ C$. With improvement of structural material in terms of allowable temperature, it becomes possible to reduce the Be$_2$F ratio to reduce the Pr number, which means the heat transfer performance increases to be available under larger heat flux as expected in the demo reactor.

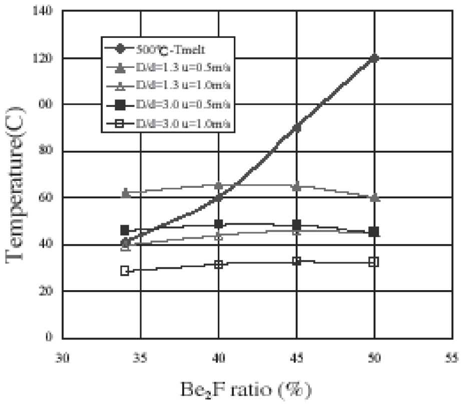

Fig.1 Temperature rise by changing Be$_2$F ratio

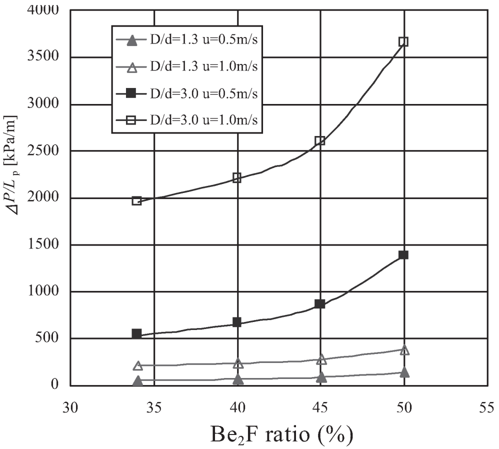

Fig.2 Expected pressure drop by changing Be$_2$F ratio